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FINAL FRONTIER

The Magazine of Space Exploration
November/December 1989

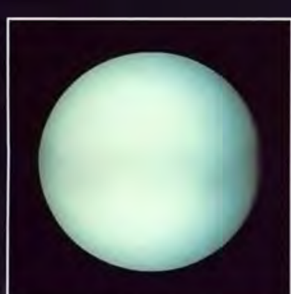
Close Encounters

Planetary Exploration's Greatest Hits • Voyager's Photo Finish at Neptune

Coming Attractions: Missions of the 1990's • Galileo's Jupiter Expedition



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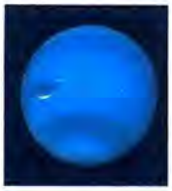

After more than two decades of quick flybys, we're about to get to know the planets in our Solar System a little better. See the stories beginning on page 18.

November/December 1989
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Features

Departments

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FROM THE PUBLISHER

1990. The beginning of a new decade.

The past ten years of space exploration covered the whole spectrum of emotion from tragedy to triumph. Then, thanks to a once-every-175-years alignment of the planets, and more importantly to the hard work of some 3,000 people over the past 17 years, the decade's grand finale at Neptune was nothing short of a "new age" miracle.

Most of us got quite melancholy over Voyager's "last picture show." With all the bye-byes, so-longs and farewells, it's only natural. Especially for those who dedicated a large part of their professional careers—a total of 11,000 work years—to making the "grand tour" possible. Hats off. There have never been two more amazing robots than the Voyager spacecraft.

Don't despair, though. Voyagers 1 and 2 will still be talking to us into the next century, or at least we expect them to, as they head off in search of interstellar winds beyond the influence of our Sun.

After that we'll be able to philosophize for years about the Voyagers' long drift through silent space, a gold record of Earth sights and sounds attached to their sides. Even the idea of these messages in a bottle reaching other civilizations embodies all our aspirations for a future that transcends the present generation.

Voyager was a first, and you can only be first once. But it was just a warm-up for the main event, as you'll see in the story beginning on page 18. In the 1990s the heavens will look like a veritable airshow of spacecraft, all sling-shotting around the Solar System as if we owned the place. Mars balloons, comet "penetrators," Saturn orbiters. Is this stuff for real? In the words of a JPL scientist as he viewed Neptune's "Great Dark Spot" for the first time, "Wow!"

The other day we were talking here in the office about the sophistication of these planned missions. As incredible as Voyager's capabilities are—and anything that can read a newspaper from over half a mile away is "incredible" in my book—it's still using computers of early '70s vintage. Just think what the new-and-improved planetary travelers will send home.

A hope of mine is that all these thrilling projects on the drawing board will inspire the younger generation to hit the books. I have a feeling that with all the binary digits bombarding Earth's radio antennas, we're going to need some new recruits to decipher what all those zeros and ones mean. I'd like to help out, but my skills are less technically bent—I still haven't figured out how to reprogram the clock in my car.

Yes, for a space exploration aficionado, it's good fortune to live in our times. Bring on the '90s. Bring on the new worlds.

Ever upward,

William Rooney

William Rooney
Publisher

FINAL FRONTIER
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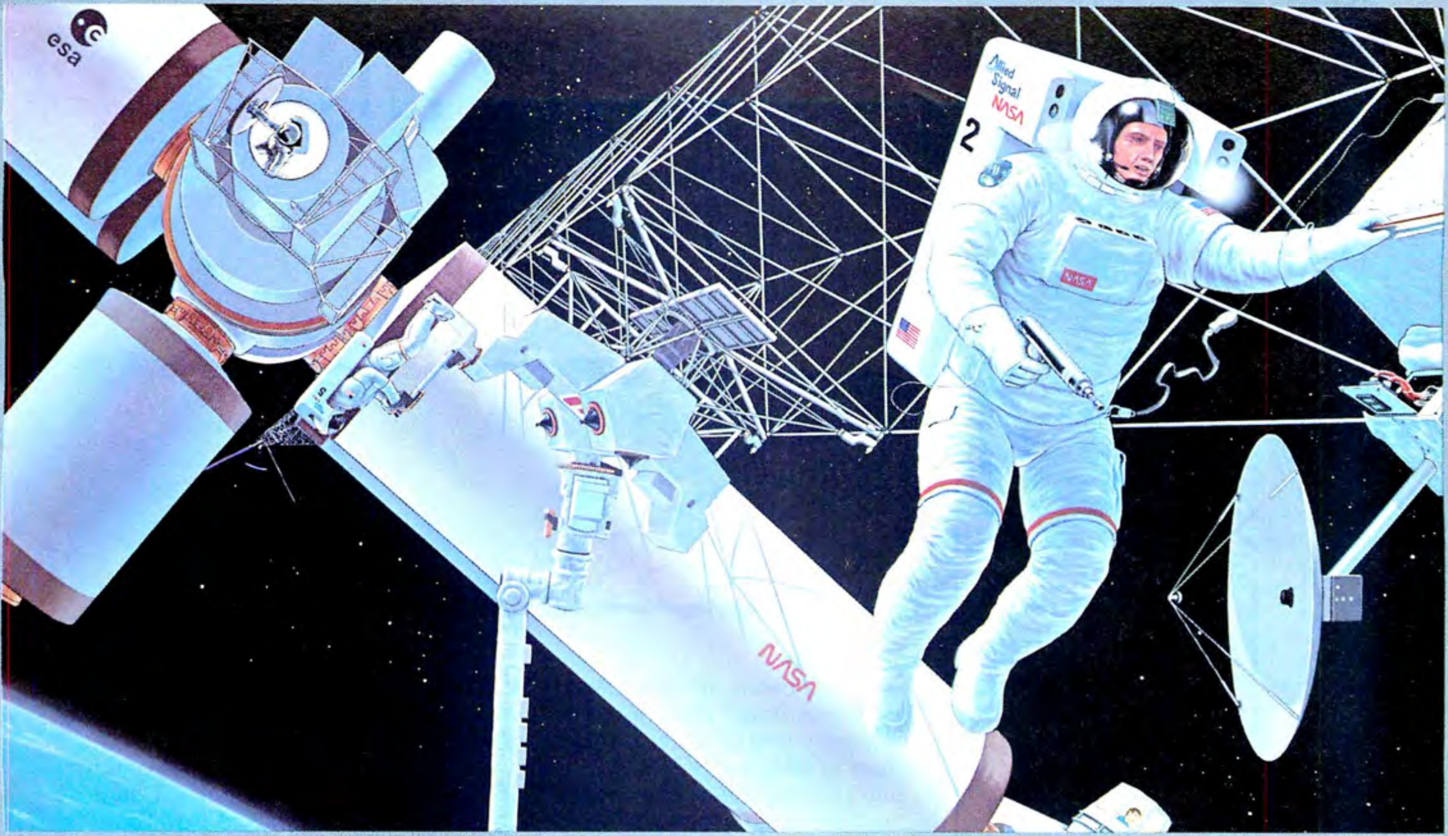
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LETTERS


TOM R. GARRETT

Cold Facts

In Bob Gibson's article entitled "Last Gas Before Mars," (October 1989), the author seems to be confused about the nature of NASA's COLD-SAT program. During our interview, I emphasized that COLD-SAT is an experimental satellite which will be utilized to develop the technology necessary to design cryogenic space systems, including cryogenic fluid depots. Mr. Gibson incorrectly equated the technology satellite (COLD-SAT) with the end product (cryogenic fluid depots). There is no intention of COLD-SAT serving "as a refueling point for missions to the Moon or the the planets."

Mr. Gibson also gives a misplaced emphasis to locating a refueling point "at a libration point near the Moon," which was only one of the secondary potential locations I mentioned in our interview. The most probable location, as I mentioned, would be in low Earth orbit, at or in the proximity of space station Freedom.

E. Patrick Symons
Chief, Cryogenic Fluids
Technology Office
NASA Lewis Research Center

Responsibility

The article, "How to Beat the High Cost of Space," by Gary Stephenson and Greg Freiherr (October 1989), at last mentions in print the collusion which has developed between NASA and its contractors. The contractors—one, in particular—are largely to blame for the situation, I'm afraid. Harrison Storms, former president of North American Aviation's Space Division, is alleged to have laid down the dictum. "Find out what the customer wants and trace it."

Congress is said to share much of the blame for the present situation, but I wouldn't hold that body to the same responsibility as NASA and the industry. When NASA lies to Congress and is backed up by a spineless group of companies, how can Congress possibly know what to do? Even the Office of Technology Assessment got all its information for its advice to Congress from NASA reports and industry collaboration. If the people familiar with the situation (industry non-management employees) can't speak up without being either threatened or actually fired, how can the truth be known? That, I think, is where publications like yours come in. The press, as in hosts of other instances (Watergate comes to mind), has a real responsibility for keeping the taxpayers informed and out of hot water. So keep it up.

Oliver P. Harwood
Huntington Beach, California

Hydrogen Economics

Your reference to the fuel cell powered by hydrogen in the October 1989 issue ("Notes From Earth") is most interesting. A number of enthusiasts have proposed that the way to solve a lot of our pollution problems is the so-called hydrogen economy. There was an excellent write-up on this in *Scientific American* several years ago, and interested parties should refer to that. This would propose to use most fuel sources for generating hydrogen which, unlike electricity, can be transferred through pipelines for vast distances, with very few losses, and can be stored cryogenically for peak load. Demand can be generated for multiple small sources, and can be produced directly by nuclear plants.

W.R. Hale, M.D.
Pomona, California

THE OBSERVATORY

Thoughts on the President's Proposal

A new initiative, and a new imperative

By Noel W. Hinners

On the 20th anniversary of the Apollo II Moon landing, President Bush proposed "...a long-range continuing commitment" to human space exploration. Reaffirming space station Freedom as the goal for the 1990s, the President envisions a permanent return to the Moon for the new century, then human exploration of Mars.

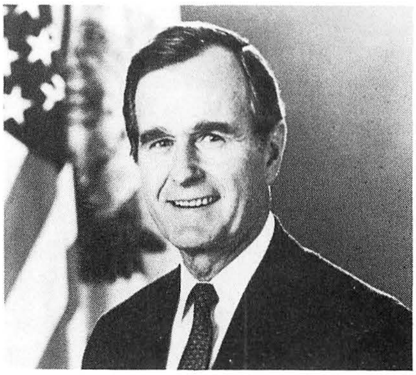
The proposal, far-reaching in its implications, is worthy of the kind of broad national debate necessary in a democratic society that must reach a consensus on its major goals. A vigorous public discussion has yet to occur, however, perhaps due to the fact that the proposal was short on implementation strategy, a challenge the President assigned to the National Space Council.

Early reaction by exploration advocates, although expressing some disappointment over the lack of specifics, generally viewed the proposal as positive and on-track. Editorial page detractors, meanwhile, haven't been as numerous nor as vocal as one might expect (a lull before the storm?). Their objections seem like *deja vu* from the 1960s, when President Kennedy's Apollo proposal drew fire from the science community and from proponents of liberal social programs. The former said that lunar science could be done much less expensively by automated spacecraft, while the latter argued that the money and brainpower would be better spent providing housing, food and health care for the needy, or restoring our inner cities to a livable condition.

Today's reaction from the scientific community is muted, partly by a recognition that human space exploration isn't–and never has been–motivated primarily by the prospect of accomplishing scientific research. It is, as the National Academy of Sciences has agreed, largely a political decision from which scientific benefits can flow. Moreover, careful analysis shows that as the total NASA budget goes, so goes the space science budget (Congress has even mandated that the space and Earth sciences shall receive at least 20 percent of the NASA budget).

Perhaps more important, the "manned" and "unmanned" sides of the space program have seen a thaw in their historical Cold War; NASA and its advisory committees are working to break down the artificial dichotomy between automated and human exploration, advocating a mix in which humans are used for what they do best (reaction to unforeseen circumstances, dexterous manipulation) and machines are used for tasks that are either dangerous, too expensive to involve people, or for which there is simply no point in sending humans.

Like Apollo, the human explorations of the next century will require site-survey engineering data that bear on mission safety. Those data–from automated orbiters and landers–also will be scientifically valuable. As to the need for a precursor automated sample return, we could conduct a Mars mission without first returning a sample, and avoid the expense; after all, Apollo was done that way, and everything worked out just fine. But the exploration of Mars will greatly exceed Apollo in cost, time and effort, and will not have the same frequency of missions. We must therefore take the fullest possible advantage of the Mars crew's time. To acquire samples beforehand, and to formulate techniques for later detailed sampling by intelligent humans, makes eminent sense. Apollo 11 would have been scientifically more productive if we'd had the samples from automated Soviet Luna missions several years before the landing.



Addressing the concerns of those who believe that human exploration is a misplaced priority compared to social programs is a greater challenge than arguing the mix of humans and machines, and gets to the basic question of "why?". President Bush, providing essential political leadership, answers with "Because it is humanity's destiny to strive, to seek, to find." Appealing to destiny, however satisfying to those who are fortunate enough to be directly involved, says nothing to explain "why now" to our citizenry.

Surely a part of the rationale should involve education–currently in a crisis similar to that of the Sputnik era. Space exploration, especially human space exploration, clearly can help motivate our youth to learn, to enquire, to apply themselves to creative purpose. Once educated, they see and appreciate the beauty of the nature we explore. Knowledge becomes a joy far better than that proffered by the temporary high of mind-killing, stultifying drugs. Our challenge is to use space exploration to kindle the inherent primacy and potential of the human spirit.

And, yes, we can send machines into space. But not as a substitute for the human venture. Let us respond with vigor and excitement to the sublime urge to "extend human presence into the Solar System," a presence which will never be transmitted by antenna.

Now Vice President for Strategic Planning at Martin Marietta, Dr. Hinners headed NASA's space science program in the 1970s, and until recently was the space agency's Associate Deputy Administrator. The opinions here are his own, and do not reflect those of the Martin Marietta Corp.

GLOBAL CURRENTS

Ticket to Ride

Britain's foray into space tourism

▼ ▼ ▼

By Mark Williamson

"Astronaut Wanted: No Experience Necessary."

So read the headline of an advertisement carried by the *London Times* and other British newspapers last July. Below this startling banner, the advert revealed that Glavcosmos, the Soviet space administration, had offered to fly a British astronaut to the Mir space station in 1991. Many an early morning commuter must have thought it was a hoax, but by the time the country's media had taken up the story, the 16-line switchboard of the astronaut hotline was jammed with callers. And by the closing date, 15 days later, almost 13,000 applications had been received.

Had the British people been affected by the uncommonly hot summer weather, or was this part of the madness associated with the media silly season? Neither. The mission, code-named "Juno," is the result of a joint venture between a British private enterprise consortium and the Moscow Narodny Bank. It will be the first entirely commercial space venture, funded by the sale of sponsorship and merchandising packages, payload space for scientific experiments and broadcasting rights. The mission's cost, quoted as 16 million pounds ($26 million), will be covered in part by the sale of advertising space on the astronaut's spacesuit and the launch vehicle.

This also will be the first time a British citizen has been into space. The U.K.'s first astronaut was to have been a military man, trained by NASA as a space shuttle payload specialist for the 1986 launch of a U.K. Skynet communications satellite. But after the Challenger disaster, the satellite was moved to an expendable launch vehicle and the astronaut candidates were returned to their earthbound posts.

The Juno mission offers the title of the first British astronaut to "the ordinary man in the street." But in the real world all men are not equal: Applicants have to be fit and healthy 21-to 40-year-olds of either sex, with a degree in science and a proven ability to learn a foreign language (the two finalists will be required to learn Russian as part of their training).

Of the 13,000 who phoned the hotline, 3,500 made it over the first hurdle by submitting an application form. By early August, they had been whittled down to 150 candidates who would undergo the first phase of medical assessment. One of those was Dave Gibbon, a 26-year-old satellite propulsion engineer with British Aerospace Space Systems. The newspaper advert had been pinned to noticeboards around his plant, where it provoked reactions from ridicule to disbelief. But in competitive spirit, and with an eye to the rewards of success, Gibbon and a number of colleagues decided to "give it a go."

Along with all the other candidates, they endured a full day of physical and psychological testing. The psychological tests, which included an analysis of mental aptitude and personality, were similar to those taken by applicants for professional or managerial posts, and included a number of yes/no questions like, "Are you happy-go-lucky?", "Do you kick animals?" and "Have you any endorsements on your driving license?" Is this how it was for the Mercury Seven?

According to Gibbon, the academic level of the applicants was surprisingly high, with a significant proportion of Ph.D.s among them. In true-Brit style, he remains "moderately confident."

ERIC HANSON

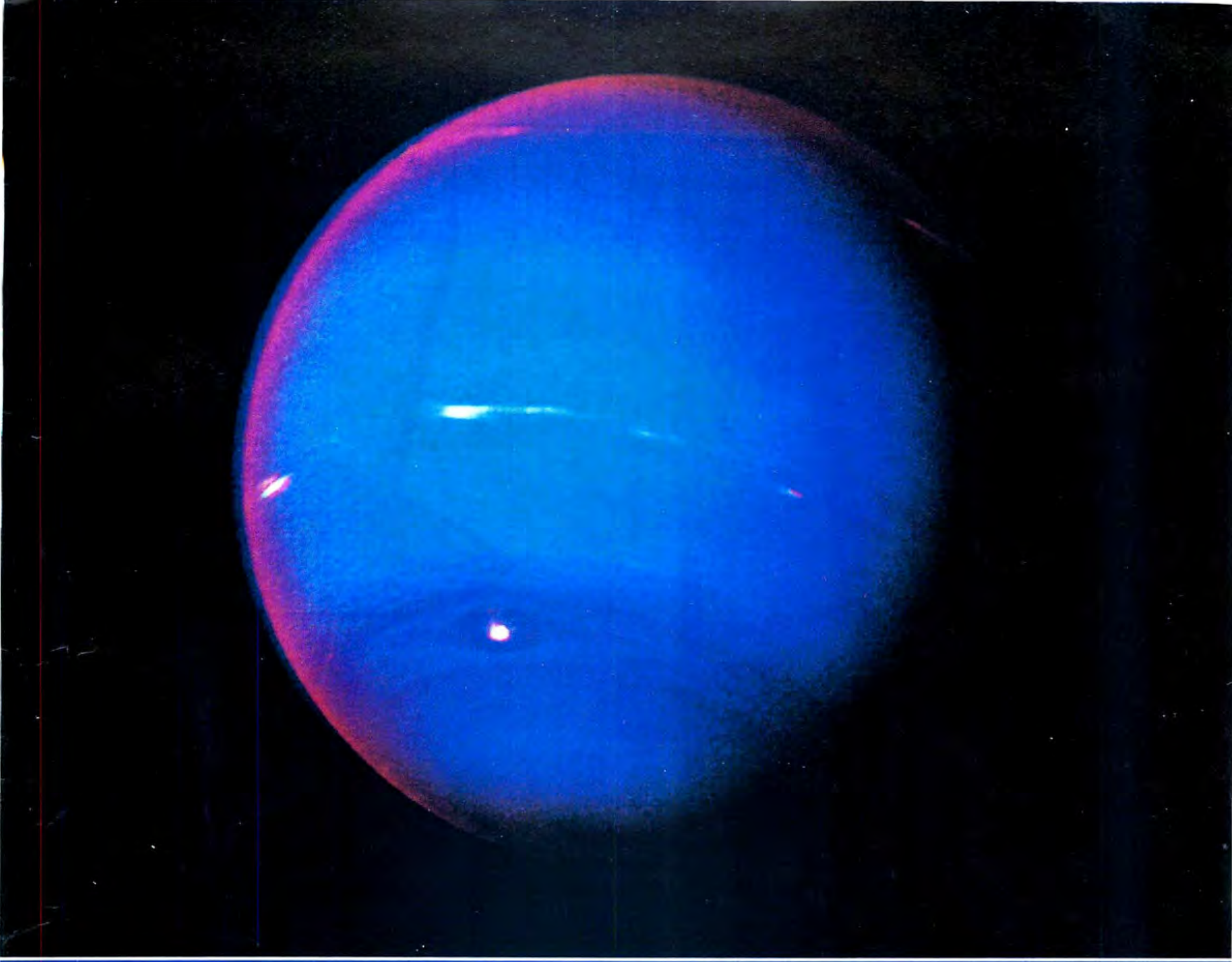
The 30 candidates picked for phase three face another round of tests, including skull and spinal x-rays, measuring the response to severe physical exertion, and what a briefing paper describes as "a number of other mildly unpleasant procedures." It later adds cheerfully that the tests will be "in no way hazardous to your health or well-being."

Fifteen "survivors" will be selected for the next phase, a series of aerodynamic tests to judge their reaction to g-forces and simulated weightlessness. Finally, the four best candidates will visit the USSR for further assessment by Glavcosmos personnel. The names of the two finalists will be announced in November, and their 18-month astronaut training program will begin.

Glavcosmos will train the two astronauts at the Gagarin Center in Star City near Moscow in preparation for an eight-day flight, due to take place between March and July 1991. Only one of the successful candidates will venture into space; the other will remain on Earth to act as a "control," carrying out identical experiments to those being performed in orbit.

The experiments, developed by British scientists and engineers on behalf of sponsors, may include pharmaceutical and semiconductor research, studies of gravity's effect on the development of organisms, and research into bone-wasting diseases. Heinz Wolff, the chairman of the experiment selection board and a well-known science popularizer in the U.K., is convinced that "the results of the experiments will add significantly to mankind's knowledge."

Not only does the Juno mission make history for Britain, it breaks new ground for manned spaceflight in general, being the first such mission to be funded by the private sector. In these times of financial stringency in government space budgets, it could be a foretaste of things to come. □



NOTES FROM EARTH

The "launch pad" for Michael Heivly's microwave space sculptures.

ZAP + BEEP = ART!

The same week that the Soviet Union launched a pair of spacecraft to the Martian moon Phobos last year, Michael Heivly sent a mission of his own into deep space. Instead of launching an expensive and elaborately designed probe loaded with scientific instruments, Heivly's "spacecraft" was a one-work microwave art show that should play throughout the galaxy.

Starting with a topographical map of San Diego's Balboa Park, the Bakersfield, California, artist gave each contour line a specific musical note. The information was fed into a computer that changed it into digital data; Heivly then used a music synthesizer to convert the data into sound.

After sending the sound through a transmitter that changed it into microwaves, the resulting energy, representing the landscape, was zapped into space by six antennas. "The result is a vast conical radio wave sculpture not unlike the solid mass of traditional sculpture," Heivly says.

Heivly has sent five other 'landscape sculptures' into space during the last five years, and is working on a similar project for the millennium. He plans to use 26-foot-tall concrete monoliths with antennas to beam into space a topographic map of part of the San Andreas fault along the Carrizo Plain of central California.

"We have to include art and poetry in the exploration of the universe," says Heivly. "Besides, most artists I know have been in deep space all their lives."

Heivly adds that the microwave energy will hold its shape for hundreds of thousands of years, giving it a longer life than any art now on the planet. But the biggest question is whether his art transmissions will be intercepted and understood by members of an alien civilization.

"I'm sure there's someone out there who is able to hear in the microwave range," Heivly insists. "And since I'm able to *encode* my art into microwave energy, I'm certain there are 'little green men' who can *decode* it."

—*Ken Wells*

OLD BIRD, NEW WINGS

When shuttle orbiter Columbia rocketed into space in August, NASA officials toasted more than just another successful launch. Columbia's fiery ascent capped a three-and-a-half-year recovery effort, as well as a race against the clock to preserve NASA's fragile payload schedule.

Much like Discovery and Atlantis, Columbia underwent a face-lift involving 258 modifications in the years following the Challenger accident. NASA's original space shuttle got an overhauled thruster system to reduce the risk of fuel leaks and to improve propellant flow. Columbia also received new fuel cells and associated plumbing, an improved set of auxiliary power units to drive the craft's engines and wing surfaces in flight, and an escape system astronauts would use if the orbiter fails to make a runway landing.

The old bird's "feathers" caused the most trouble in readying Columbia for STS-28. Roughly 8,000 thermal tiles on the spaceliner's payload bay doors and mid-body were removed and replaced with the newer, lighter thermal blankets used on Discovery and Atlantis. Each tile had to be removed by hand and the replacements tested to assure bonding to the aluminum skin underneath.

Since Columbia had been built in the late 1970s, before any winged craft had actually orbited, it weighed nearly 7,000 pounds more than later shuttles. The weight savings of the insulation blankets was essential if Columbia was to match the performance of its

stablemates. In fact, tile rebonding and replacement continued even after the orbiter was stacked with its external tank and solid boosters, with some work completed on the launch pad itself.

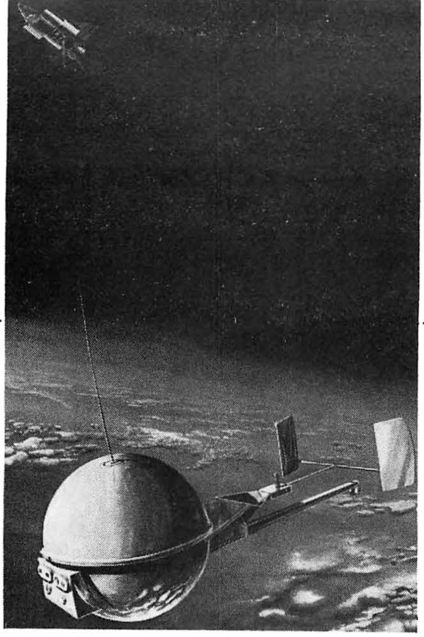
When Columbia rolled out to Pad 39B in late summer, it looked almost new. It still sported its unique wing markings (a simple "USA" and American flag), along with the distinctive black "V" of high-temperature tiles on the gloves of the inner wings. Only her name was moved, to the outside of the crew module, due to the new insulating blankets on the cargo bay doors.

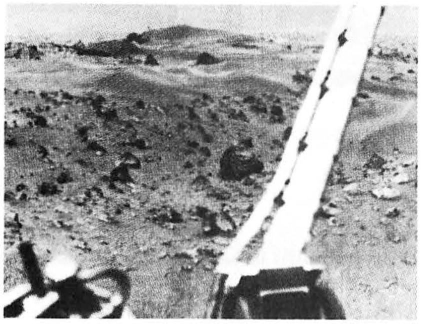
Officials at the Edwards Air Force base landing site pronounced Columbia clean as a whistle after its classified mission. Said NASA's associate administrator J.R. Thompson following Columbia's return: "She may be an old bird, but she's still got a lot of life in her."
—*Frank Sietzen, Jr.*

DEJA VIEW

American and Soviet hardware probably will return to the surface of Mars sometime before the turn of the century. Exotic, unexplored areas such as the massive extinct volcano Olympus Mons and the sprawling Mariner Valley often are mentioned as candidate landing sites for a sample return mission.

With all that nifty real estate untouched by robotic hand, why does





A tethered satellite like the one above could sample the Martian atmosphere. Chryse Planitia (bottom) may be revisited by robot explorers.

Bob Craddock want the next Mars explorers to touch down in "our own backyard"—Chryse Planitia, site of the 1976 Viking 1 landing?

"The best reason is that we've already been there," says Craddock, a researcher with the National Air and Space Museum's Center for Earth and Planetary Sciences. "The Viking lander photographs have given us ground truth observations as to what the surface of Mars is like, and a sample from a *known* location is needed to understand the history and evolution of Mars."

Craddock points out that Martian geological history presently is divided into three "ages" based on the density of craters observed on past missions, but the absolute time frame of each age is unknown. The Viking 1 lander sits atop materials from a period of widespread volcanism and channel formation; Craddock believes a sample of Chryse Planitia, brought back to Earth for radiometric dating, would allow us to date practically every other event on Mars.

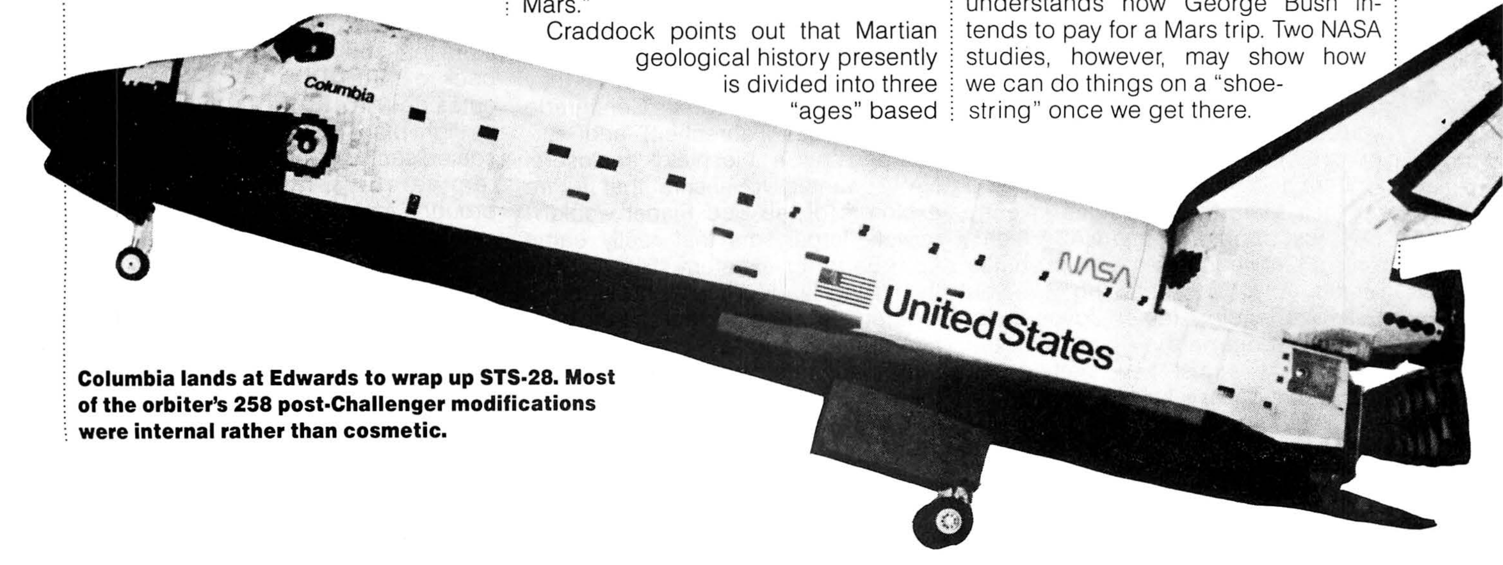
"Rocks seen by the lander could also be brought back to settle the debate concerning composition and erosional properties," says Craddock. "And the crater caused by the jettisoned Viking aeroshell is within a kilometer of the Slander: samples from this [new] crater's ejecta represent the upper few meters of the surface, saving the trouble of placing a drill on the rover."

Craddock admits that some other sites might have a wider variety of geologic materials, but the chance of a successful landing—and the scientific payoff—are unknown. His ultimate solution? Go back to doing things the "Viking way."

"If the rover mission flies in a pair as planetary missions did in our heyday," says Craddock, "then the first could return to Chryse Planitia—and the *second* could land in someone else's backyard."
—*Les Dorr, Jr.*

THE REEL THING

No matter how they read his lips, neither friend nor foe understands how George Bush intends to pay for a Mars trip. Two NASA studies, however, may show how we can do things on a "shoestring" once we get there.



Columbia lands at Edwards to wrap up STS-28. Most of the orbiter's 258 post-Challenger modifications were internal rather than cosmetic.

TROY THOMAS

Alan Stern of the University of Colorado and Eric Rice of Orbitech, Inc. in Madison, Wisconsin, both have won contracts to study the technology of using miles-long tethers deployed from spacecraft in orbit around the Red Planet. In both cases, creativity may be the mother of affordability.

"Every two years Mars has a massive dust storm that extends upwards about 300,000 feet. We hope to show that we could reel down a collection device from orbit to pick up samples of this dust," Stern explains. "If you leave it for a few days, you would get about a pound of Martian dust. You could also keep reeling it down and back to get more and more samples."

Rice's idea is to snake a hollow tube down from orbit and scout out carbon dioxide in the Martian atmosphere. He believes that the CO_2 could be used as a low-power rocket propellant. "The idea is to use the resources that are available wherever you can find them. If you can find it in orbit, you don't have to bring it there," says Rice.

Stern and Rice should be wrapping up their Mars tether studies in early 1991, just about the time NASA flight-tests a 12-mile-long tether from shuttle orbiter Atlantis. According to Ivan Bekey, a leading tether advocate at NASA headquarters in Washington, the technology is just now getting the attention it deserves.

"People like complicated, sophisticated, engineering challenges. Tethers are so simple that they haven't been taken seriously," says Bekey. "People have always thought in terms of rockets and new technologies, when in reality you can use the simple, fundamental laws of physics to do the same job."

"We want the country to want to go to Mars," Stern says, "so we want NASA to have all the options, not just the classic ones." —*Maura J. Mackowski*

GERM OF AN IDEA

Environmental impact studies don't stop at the fringes of our atmosphere. As we think seriously about returning to Mars, mission planners are reconsidering a decades-old question: How do we protect Them from Us and Us from Them?

Before the twin Viking spacecraft headed out to Mars in the 1970s, they were baked at 113 degrees Centigrade (235 degrees Fahrenheit) and surrounded by a bioshield enclosure. NASA wanted to ensure that future explorers of the Red Planet wouldn't mistake organisms that really came from Earth for extraterrestrial life. But the Viking landers found no signs of indigenous organic critters on the Martian surface, and few scientists think there's any real chance that life exists there now.

In 1984, the international Committee for Space Research (COSPAR) issued a new policy that abandoned stringent quantitative requirements for contamination protection in favor of more flexible, qualitative guidelines that consider where you're going and what you're going to do when your spacecraft gets there. For example, the possibility of life on the gaseous outer planets is remote, so the Galileo spacecraft underwent some cleaning, but no real sterilization.

Still, safeguarding the Red Planet figures into the blueprints for future missions. NASA has revitalized its "planetary protection" program, and a workshop for exo-biologists and mission planners is set for early 1990.

Attempting an automated sample return—a prime candidate for a late 1990s mission—also raises another issue. What if there *are* organisms on Mars that could, in turn, be transferred back to Earth? That possibility complicates design of both a spacecraft and its flight plan. The sample itself must be sealed securely, loaded into an uncontaminated return craft and then brought millions of miles home to a safely quarantined lab.

The consensus seems to be that as long as we don't really know what's out there, it's probably best to ensure that any robotic foot we plant on the Martian surface doesn't leave an imprint we can never erase.

—*Ray Spangenburg/Diane Moser*

Follini in isolation: serious science or circus stunt?

AP/WIDE WORLD PHOTOS

LEGACY OF THE CAVE WOMAN

Earlier this year, Stefania Follini emerged from Lost Cave near Carlsbad, New Mexico, after 130 days in voluntary isolation—the world's record for a woman. But now that all the media hype has subsided, researchers are divided over whether the experience of the 27-year-old Italian interior decorator was a valid scientific experiment or little more than a stunt.

There was considerable conjecture about NASA's involvement with the project, but the space agency emphatically put such questions to rest. "NASA did not participate in any formal way with this experiment, nor did we supply any funding for the project. Right now, all NASA's plans involve missions with several members [not just one person] in the crew," said Pam Alloway at Johnson Space Center.

Yet some experts here and abroad maintain that isolation studies have important implications for space voyagers. Jon DeFrance, a neuropsychologist who specializes in human performance and attention disorders at the University of Texas Medical School in Houston, says that although the space agency didn't formally support Follini's endurance test, its design is right up NASA's alley.

"We know from previous studies that isolation can interfere with cognitive and motor functioning. Some subjects even become 'desynchronized' in their body temperature and hormonal levels," DeFrance explains. "If we're looking at a manned flight to Mars that will require 18 months, then we must be concerned about the findings associated with Ms. Follini."

Researchers are still unravelling the great amounts of data from daily blood pressure checks, urine and blood samples and brain wave (EEG) tests done during Follini's isolation. She initially demonstrated decreased concentration and short temper. Within about two months, however, she seemed to adjust to the environment and passed her time reading, cooking, exercising and playing cards.

Because she lacked ordinary temporal cues, her "day" stretched to 24 hours of wakefulness and 10 hours of sleep toward the end of the experiment. She also stopped having menstrual periods, which may be connected to her weight loss of almost 20 pounds.

"These kinds of experiments provide unique insights into our basic biological functioning," says DeFrance. "To my way of thinking, that's very valuable knowledge."

—*Anene Tressler-Hauschultz*

OH, MY ACHING TRUSSWORK

As you'd expect, Space Station Freedom will be able to alert its crew if a computer system goes on the blink or a valve sticks somewhere in the plumbing. But engineers at Florida Institute of Technology also would like the orbiting complex to be able to tell the astronauts when it's just... *tired*.

With the emphasis on increased flight safety in the post-Challenger era, NASA is among the government and commercial interests funding FIT's work to develop space and Earth-bound applications of "talking metal" materials that incorporate embedded optical fibers.

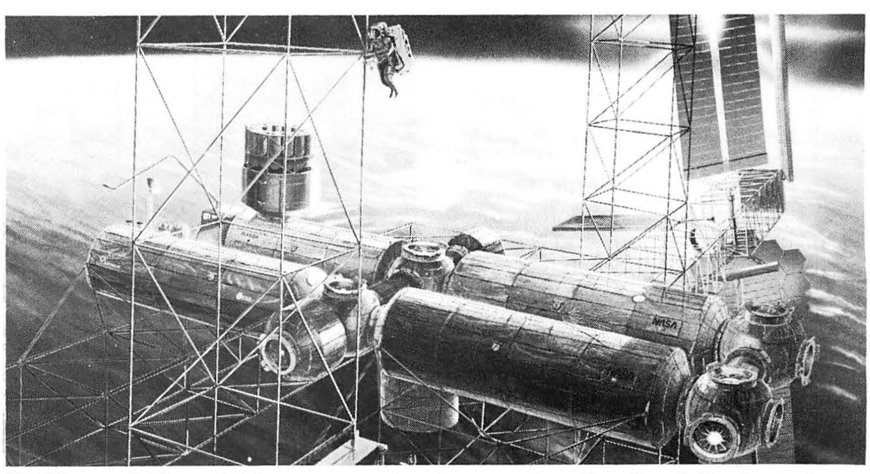
In complex space structures like Freedom, lunar bases and Mars ships, the integrated system of tiny light cables would serve the same function as the neural network in a human body. They would create an artificial nervous system capable of sensing degeneration in their host material and informing the astronauts of the problem.

"NASA is interested in talking metal for the space station," says Barry Grossman, leader of the electrical engineering team studying talking metal at the Melbourne, Florida, college. "The fiber optics are so thin and small that they don't add any weight."

The Florida researchers also are studying how fiber optics might be used to "treat" a problem as well as diagnose it. Grossman points out that transmitted light could be used to generate heat in a fatigued area, causing the metal to assume a new shape and — potentially — correct the condition.

Two tests of talking metal applications are tentatively scheduled for 1990. "FIT has a big aviation school, and we have received permission to put optical fibers on the wings of an airplane and monitor a test flight," Grossman says. A similar test will put fiber optics in the concrete of a building to measure the effects of weather and ground movement.

—*Joseph Baneth Allen*



"Talking metal" may let large space structures such as Freedom tell astronauts where it hurts.

Boundaries

Sailing the Light Fantastic

The best little yacht race in the Solar System

▼ ▼ ▼

By Patricia Barnes-Svarney

Christopher Columbus would hardly recognize these vast sheets of reflective material pushed by Sunlight as sailing ships. No poop deck, no hull. Nobody walking the plank. Yet he'd readily identify with their objective: to voyage into the unknown in search of fame and treasure, or at least a modicum thereof.

A small fleet of "solar sails" may soon be rigged and readied for a fantastic race to Mars as part of the celebration to commemorate the 500th anniversary of Christopher Columbus' overseas trip. "There is one basic requirement—to deliver a one-kilogram plaque to the final destination, Mars," says Klaus Heiss, project chairman for the "Columbus 500 Space Sail Cup," as the competition is dubbed. "We hope to have one sail each from Europe, the Americas and Asia, the three zones connected with Columbus' voyage."

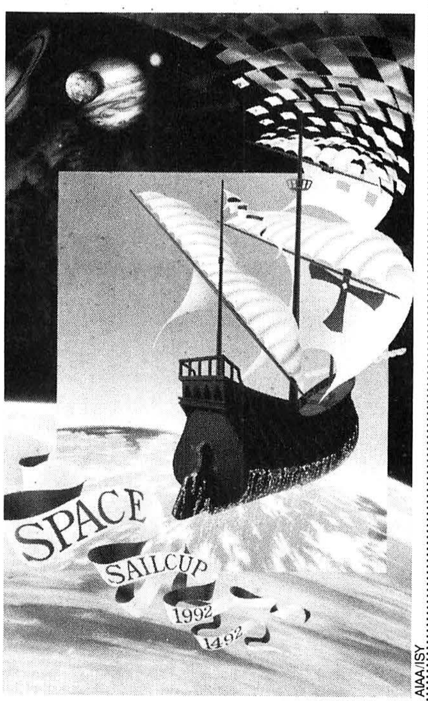
One of the contest's major rules is that no government funding is allowed. Corporate sponsorship is welcome, however, considering that the sails may each cost \$3-5 million to build. Ball Aerospace has agreed to sponsor an entry from the U.S. Naval Academy, while a sail from the University of Washington is being backed by Boeing. Already, more than 30 groups worldwide (half in the United States, but some in China and the Soviet Union as well) have shown interest in participating in the race.

The World Space Foundation in South Pasadena, California, leads the pack; they've had an interest in solar sailing since the early 1970s. France's U3P (Union pour la Promotion de la Propulsion Photonique) and a Japanese university affiliated with that country's Institute for Space and Astronomical Sciences also have pioneered solar sail development.

Over the next few months, the American Institute of Aeronautics and Astronautics will judge the technical feasibility of vehicle designs submitted by potential race contestants. The evaluations will then be given to the Space Sail Cup Committee of the official Columbus anniversary "jubilee" commission, which will select the winning designs by December 1990. The three sails chosen as "flagships" will be named, appropriately, *Nina, Pinta* and *Santa Maria* .

Instead of burning fuel, solar sails take advantage of the slight but steady pressure of photons from the Sun, which strike the lightweight, ultra-thin reflective material, propelling it away from the Sun at increasing speeds. In the vacuum of space, a 10,000 square-foot solar sail can eventually exceed 124,000 miles per hour.

"Solar sails are relatively inexpensive, they can be built in two to three years, and can be boosted to a low Earth orbit with a smaller rocket, say a Scout-class vehicle," says Heiss. "Instead of a billion-dollar planetary mission, you suddenly are looking at missions costing around \$50 million, a fantastic breakthrough."



The "Columbus 500": Sail of the century.

The "racing" vehicles should take about two years to reach the Red Planet, because the sails will accelerate very slowly. To keep interest up, awards will be presented at various milestones along the way—to the first sail to open and operate successfully for a given period of time, the first to escape into planetary space and the first to pass the Moon.

Organizers hope the project will spawn advances in engineering, science, computer technology and particularly miniaturization. The Mars plaque is the only required payload, but microtelevision cameras may also be included onboard to return optical images of the sail deployment and flybys. Small scientific experiments may also be included, and could even be determined by a separate competition.

Some participants, like Rob Staehle of the World Space Foundation, resist the idea of a race as the only forum for developing solar sail technology. Although the Foundation is preparing to enter the contest, says Staehle, it "will also entertain alternatives, such as a multi-nation solar sail deployment patterned after the recent exploration of Comet Halley."

Heiss, who was one of the initiators of the Columbus 500, argues that competition is the best way to go: "Everyone has the same ground rules. We have workshops, and people can exchange information. There are many different ideas on how to make a sail, and cooperation could stifle [some of those] ideas."

The "sail of the century" is far from underway—plans are in the most preliminary stages, and no launch vehicle has even been chosen to boost the sails into orbit. But all would-be solar sailors are advised: Vehicle designs for the race are due in mid-November, and Heiss hopes that as many as a dozen finalists will be chosen by the end of this year. □

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THE PRIVATE VECTOR

Cheap Trek

The Lunar Prospector offers a bargain for Moonship shoppers

▼ ▼ ▼

By W. Daniel Leonard

It's straight out of Jules Verne—a do-it-yourself flight to the Moon.

The Space Studies Institute (SSI), based in Princeton, New Jersey, hopes to raise some $10 million to launch the world's first privately funded planetary spacecraft, dubbed the "Lunar Prospector Probe," to finish the mapping of the Moon's chemical composition that began with Project Apollo.

Contrary to popular belief, says SSI's Gregg Maryniak, Apollo didn't do a very thorough job of exploring the Moon. The later Apollo flights mapped most of the lunar surface chemistry within 30 degrees of the equator, but follow-on missions that would have completed the job were cancelled. As a result, much of the Moon is still geologic *extra-terra incognita*.

"We want people to know what the heck the Moon is made of," says Maryniak. "Hopefully we'll be able to say, 'There's ice in them thar hills!'"

Water ice means hydrogen and oxygen, which in turn means rocket fuel, or at least the raw materials from which to make it. Maryniak is convinced that finding these raw materials outside the pull of Earth's gravity would allow inexpensive launches of a variety of spacecraft from the Moon. An abundant supply of water and oxygen would facilitate plans for a human outpost.

Although the Apollo-era searches of the Moon's equatorial region turned up no evidence of ice, past or present, some scientists still believe there may be billions of tons trapped at the bottom of deep polar craters where the Sun hasn't shone in billions of years. But how can you search those areas for under $10 million?

SSI plans to do it by scrounging and begging. Maryniak says that the Institute is currently negotiating with several launch operators to hitch a free ride for the Lunar Prospector. One strong possibility is to use one of the surplus Atlas rockets the government has offered to private, non-profit organizations. Although he won't comment on the details, Maryniak expects one of the freebie deals to pan out soon.

The probe's only science instrument—a gamma ray spectrometer to chemically analyze the Moon's surface from lunar orbit—is being donated by NASA's Jet Propulsion Laboratory. It's been sitting on a shelf since the Apollo mission it was originally built for was scrubbed, but Maryniak says the equipment was recently tested and is fully functional.

As for the rest of the probe—communications, electrical power and propulsion systems—Maryniak says that several experienced spacecraft manufacturers have assured him that a single-function lunar probe can be built for $5–10 million. Labor? That's free, too. All the designing and planning for the mission is being done by a team of 25 volunteers.

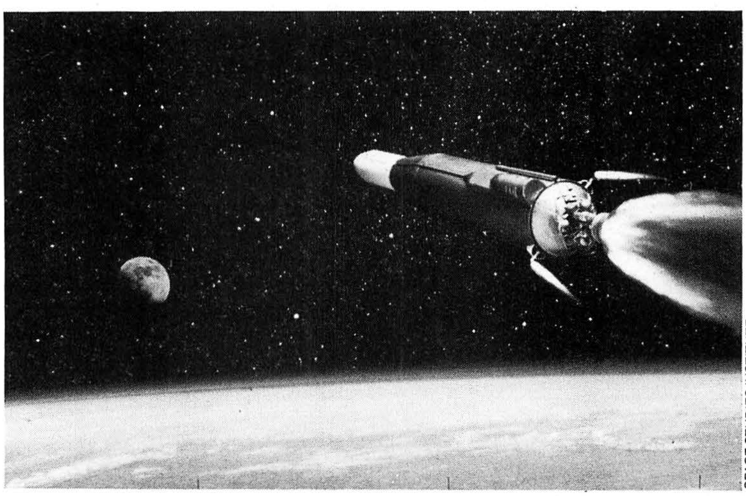
But the project is not without its problems. The gamma ray spectrometer SSI plans to use can detect hydrogen down to one meter below the lunar surface, but can only distinguish concentrations greater than 800 parts per million—the equivalent of a motherlode.

Several scientists at a special session of SSI's Conference on Space Manufacturing last May questioned the merit of sending a probe with such low resolution, arguing that it would only be able to determine whether there is a *huge* quantity of hydrogen on the Moon—about 40 billion tons per 60 square kilometers. Learning whether smaller, but still significant, quantities of hydrogen are present would have to wait until the next generation of gamma ray spectrometers is ready.

But Maryniak asserts that "there are some very fancy things we can do to increase the sensitivity of the Apollo technology and make it up to ten times better. Sure, we could use a much better detector, but that would destroy our plan to do this quickly and cheaply."

SSI had been aiming for a Lunar Prospector launch in 1992 to complete an inventory of lunar resources before NASA's decision on whether the Moon or Mars is to be our next celestial port of call. President Bush's July 20 speech outlining a return to the Moon followed by a mission to Mars may make the mission even more timely. NASA's only planned Moon probe, Lunar Observer, won't fly until the mid-1990s.

Beyond its scientific value, Maryniak claims the Lunar Prospector's success would also accomplish a secondary goal: Proving to the world that a pint-sized, private spacecraft can contribute a king-sized chunk of information to the global pool of space knowledge. □



SPACE STUDIES INSTITUTE

Lunar Prospector heads Moonward atop a surplus Atlas.

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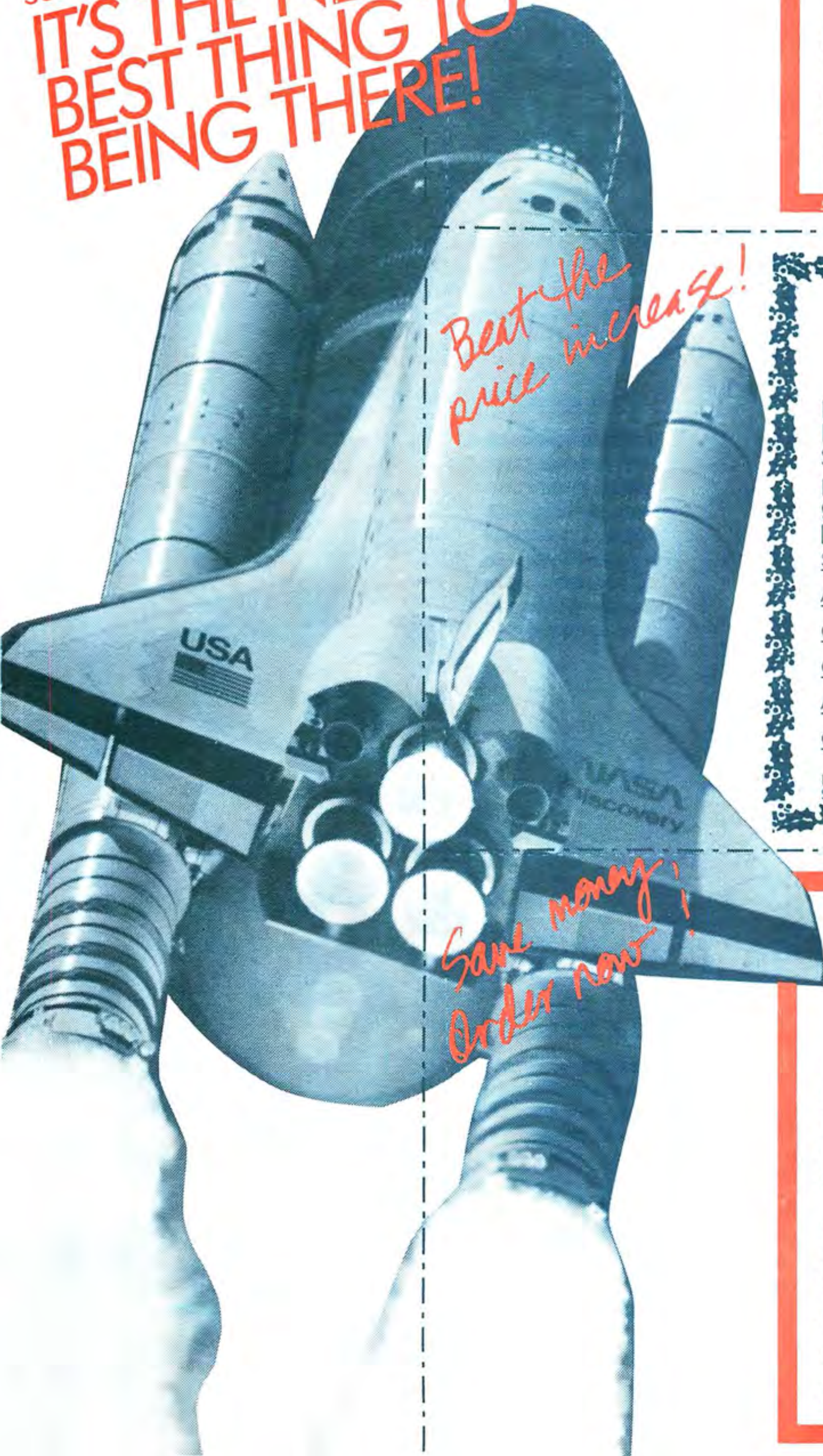

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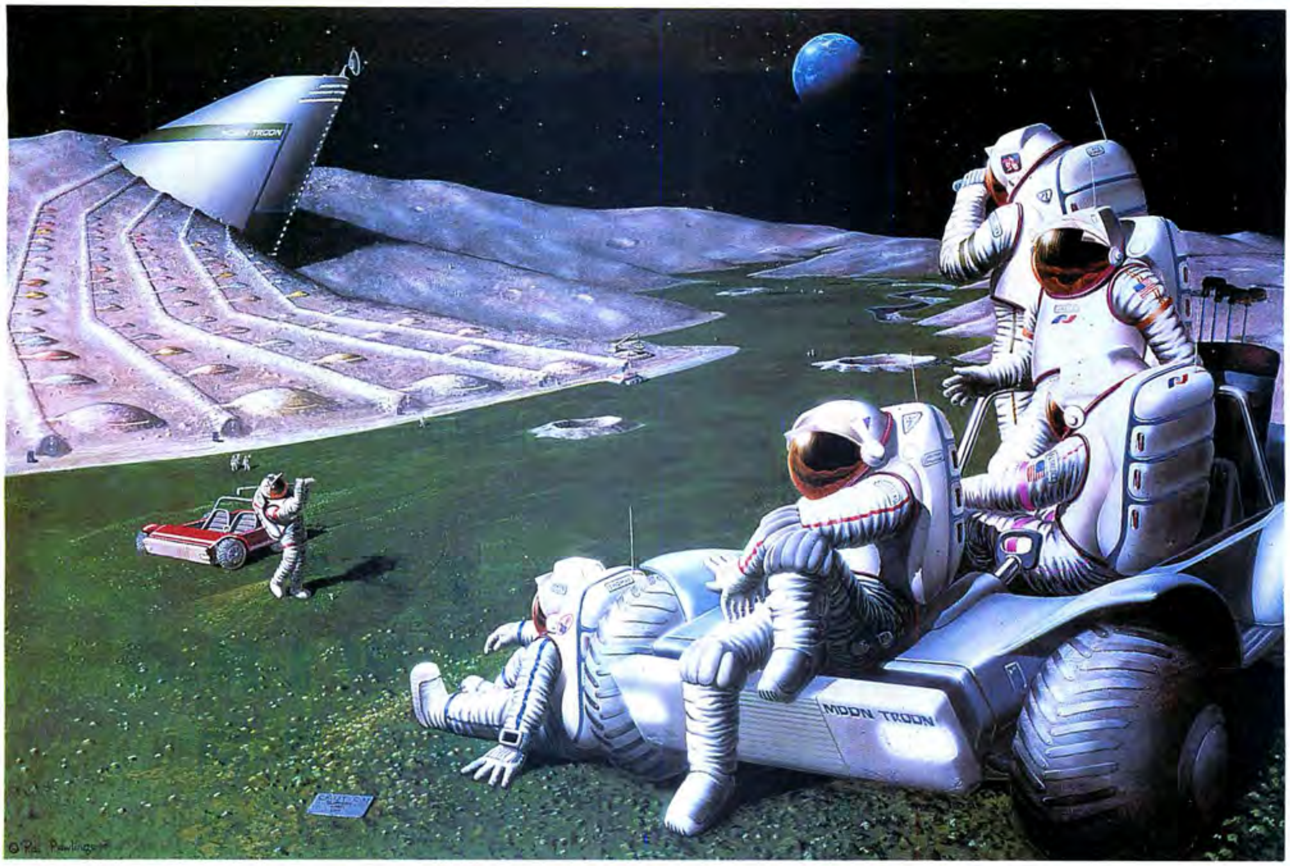

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New Worlds

Just when it looked like it was all over, a second "Golden Age" of planetary exploration is about to begin.

THE DRAWING BOARD

Lennard Fisk, the man in charge of NASA's space science program, has been singing the same tune ever since he took office in the gloomy days right after Challenger: Don't worry, be happy. The best is yet to come.

Now, at last, Fisk has the evidence to back up his boasts. Planetary exploration is *back*. The Magellan probe launched last May is on its way to a 1990 rendezvous with Venus, and the Galileo Jupiter spacecraft was headed for the launch pad as we went to press (see page 28). Just counting the missions that are already funded, there's continuous action planned from now until September 2006.

Take the year 1995, for example. A month before the Mars Observer ends its two-year mission in September, the Comet Rendezvous Asteroid Flyby (CRAF) will be launched. Three months later, Galileo arrives at Jupiter for a 22-month stay. The following April, Cassini heads off for Saturn.

Nor will this be an all-American show, the way the first "Golden Age" was. Virtually every project features significant international cooperation. In some cases, like the Rosetta comet sample return or the Soviet Mars 1994 project, non-U.S. countries are taking the lead. In others, like CRAF and Mars Observer, they play a major part.

The era of first-time looks at the planets of our Solar System has ended, but don't mourn it. Having made our neighbors' acquaintance, now we'll get to know them better.

MERCURY

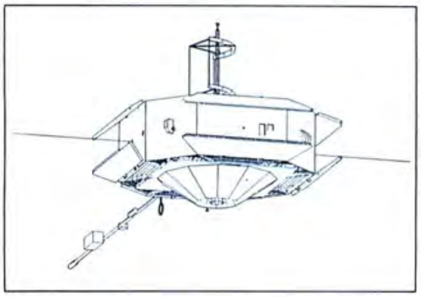
Poor Mercury. The tiny, barren, innermost planet has only been visited on one occasion, and then just barely—three quick passes by Mariner 10 in 1974–75. Mariner photographed just over half of the planet at not very high resolution, and showed the surface to be battered and moonlike. Mercury has a magnetic field weaker than Earth's but similar in shape, no atmosphere to speak of except for the wispiest traces of sodium, and the most extreme temperature differences between Sun and shadow of any body in the Solar System.

All in all, a not-terribly-exciting place for planetary geologists, who, if they want craters, can find as many as their hearts desire a mere 250,000 miles from home.

Space physicists, though, are interested in how the planet and its magnetic field interact with the torrent of radiation streaming from the nearby Sun. So NASA's Space Physics division

BY TONY REICHHARDT

Magellan's radar mapping mission (left) will complete the first phase of Venus exploration, while Mercury and the Moon (bottom) await future orbiters. A Mercury Orbiter (bottom left) would have radio antennas (top) and instrumented booms extending from a spacecraft "bus."



has been funding since 1988 a conceptual study for a future **Mercury Orbiter** mission. A team at the Jet Propulsion Laboratory has outlined a "moderate" project—meaning not too expensive—that would place two spacecraft in complementary orbits around the planet for a terrestrial year, or four Mercury years. The target launch date, at least for study purposes, is August 1997.

The road to Mercury would be long and indirect, involving two gravity assists each at Venus and Mercury before settling into Mercury orbit in 2002. The orbiters would carry mostly "fields and particles" instruments such as magnetometers and energetic particle detectors, and would be set spinning in order to sweep their sensors through the planet's magnetosphere, as well as to evenly heat a spacecraft that would be travelling dangerously close to the Sun.

For the amusement of the geologists, there would be some kind of imaging system onboard as well. During the closest part of each egg-shaped orbit, the cameras would photograph the surface—including those regions that Mariner 10 never saw—with a resolution of half a mile or better. In that way, the Orbiter would do for Mercury what Mariner 9 did for Mars in 1971, which was to quantum-leapfrog our understanding of the planet by conducting a prolonged study instead of a quick, impressionistic flyby. You never know—before Mariner 9, Mars also was thought to be dead and dull.

Another option, which would add complexity and cost to this or any follow-on mission, would be to drop a series of penetrators down to the planet (preferably in the darkness of the long Mercurian night, to avoid scorching the electronics) that would gather seismic and chemical data on the surface. At a recent international conference, Soviet space scientist Valery Barsukov of the Vernadsky Institute tossed out a similar Soviet mission concept that would send either a lander or penetrators to Mercury in 2002–2003.

VENUS

The Next Logical Step (to use NASA's overworked phrase) in the exploration of Venus has already been taken. The launch of **Magellan** from space shuttle Atlantis last May (*Final Frontier*, June 1989) not only revived the flagging U.S. planetary program, it gave mystery-lovers something to look forward to. Magellan's radar map of the hidden Venusian surface should give us our first detailed looks at mountain ranges, fault zones and perhaps even ancient seabeds, if they exist. In terms of raw data, the probe will return more information than all previous U.S. planetary missions combined.

But after this high-resolution global map is complete in April 1991, Venus exploration hits something of a brick wall. Soviet Venera landers have already returned (a handful of) images of the orange-brown surface and sampled its chemical composition. French balloons and American descent probes have analyzed the atmo-

Before the human expeditions will come the Mars precursor missions. Right: Mars Observer will investigate the planet's chemistry, weather and gravitational field from a low, circular orbit. Below: A Mars Rover Sample Return will have to be smart enough to find a safe route across rugged terrain. While robotic arms dig for samples, stereo cameras on a T-shaped mount will survey the scene.

sphere. Now comes the hard part.

In order to survive on the hellishly hot surface of Venus, where the noxious atmosphere crushes down with nearly 100 times the pressure of Earth's, a lander would need to be built like a bathysphere, with electronics and a power source capable of functioning in temperatures hot enough to melt lead. In other words, any long-lived surface mission—most likely a seismic monitoring network, or a sample return mission that would bring Venusian rocks to Earth—is well beyond current technology. Someday, maybe. But for the time being, NASA has no plans for Venus exploration after Magellan.

Japanese scientists at the Institute of Space and Astronautical Science (ISAS) in Tokyo, meanwhile, are discussing the possibility of a relatively simple, low-cost **Venus Orbiter** mission to study the interaction of the solar wind with Venus' upper atmosphere. The Venus Orbiter would be small, weighing on the order of 500 pounds. Its wide, looping orbit would bring it as close as 180 miles to the planet on the Sun side, then swing out to sample the region 30,000 miles "downwind" with fields and particles detectors.

The mission could be launched in 1995 or 1996, if approved, but it will have to compete with other proposed Japanese projects to survive. In December, officials at ISAS expect to decide whether the Venus orbiter, a cometary coma sample return mission or a lunar orbiter will be Japan's first foray into planetary exploration.

Meanwhile, the Soviets, who've had the most successful and intensive program of Venus exploration of any nation, have sketched out a 1998 mission that would land six to eight penetrators at different points on the planet to determine the chemical composition of surface rocks. Whether a Venus mission can survive the Soviet approval process to become a real project is another question.

The Moon

You heard him. We all heard him. On July 20, 1989, an American President actually stood in front of a national television audience and said we're going "back to the Moon...and this time back

Scenes From the Golden Age

"I advocate that we emphasize in our space strategy looking for the first time at new worlds," wrote Bruce Murray, former director of the Jet Propulsion Laboratory, in 1968. "If there is a chance to go with something exciting now, do it...if it is really going to increase our understanding, go, go, don't wait."

Well, we didn't. The past twenty years have been a golden age of space exploration, during which we've mapped the broad reaches of the Solar System much as Captain James Cook charted the Pacific in the 18th century. The oceanographer Roger Revelle wrote that "Cook's epitaph is the map of the Pacific, almost as we now know it." The Mariners, Pioneers, Vikings and Voyagers have defined the Solar System for future generations in much the same way.

Along the way, there have been many moments of drama and discovery. July 20, 1976, seven years to the day after the first Moon landing: early morning radio reports from Viking 1 showed that the spacecraft had made it through the atmosphere of Mars. Now, safely on the surface, it would turn on its TV camera and photograph the surrounding terrain, building up the image in a slow

The most intensely studied Solar System objects in the 1990s will also be the smallest. The European Giotto spacecraft photographed Halley's Comet in 1986 (below), but no one has ever seen the face of an asteroid. NASA's Comet Rendezvous Asteroid Flyby (CRAF) mission will study both a comet and an asteroid at close range.

scan, line by line.

Within NASA auditoriums at the Jet Propulsion Laboratory and at the Ames Research Center the tension was palpable as the first lines appeared on a wide screen, starting from the far left. As minutes went by, a picture of a new world emerged. So this is what Mars looked like! It might have been the Mojave Desert: flat, with a sharp horizon and sandy soil, vast numbers of rocks filling the scene. The scenery was barren, but that didn't matter. What mattered was that we were there.

Viking's line-by-line scan recalled the painfully slow transmission of Mariner 4's first photos from Mars, in July 1965. These had taken days to transmit, and then to enhance electronically to bring out detail. They showed a Mars shockingly unlike the canal-laced world of our imaginings. Instead we saw craters, and only the thinnest of atmospheres.

It was years before the true character of Mars would be revealed. Mariner 9 reached the planet in 1971, only to find it shrouded in a Mars-wide dust storm. As the dust cleared, though, the surface emerged in stunning detail. Here were mountains more than twice as high as Everest, and a great gash in the surface, like a Grand Canyon the length of the entire United States. Even more exciting, the photos showed traces of ancient rivers, which told of a Mars that may once have supported life.

On the very first planetary mission–Mariner 2's flyby of Venus in 1962–Earthbound scientists stayed up until dawn and watched with wonder as the first data came in. For sheer audacity, one has to admire the Soviets, who've repeatedly landed Venera spacecraft on the sizzling surface of Venus, taking photos for an hour or so before their well-insulated cameras succumbed to the heat.

The outer Solar System has had noteworthy visitors, as well. In March 1979, as Voyager 1 approached Jupiter, scientists knew that the Jupiter system was more than immense; indeed, it had features with no earthly counterpart, like the Io flux tube, a permanent current of a trillion watts and five million amperes flowing between Jupiter and its satellite Io. As Voyager approached its target, three scientists–Stan Peale, Pat Cassen and Ray Reynolds–predicted Io would be stranger yet.

"One might speculate that widespread and recurrent surface vulcanism would occur," they wrote in *Science* on March 2. Io, they declared, would flex and strain due to enormous tides raised within its body by the combined action of Jupiter's fearsome gravity and of the nearby satellites Ganymede and Europa. This flexing would produce enough heat to melt virtually the whole of Io, leaving only a thin solid crust to cover its molten interior.

Three days later, Voyager's photos showed that the moon was in fact covered with volcanoes and magma flows from pole to pole. Some were even still erupting, and Io was instantly recognized as the most geologically active body in the Solar System.

Voyager saw much more. Jupiter's enigmatic Great Red Spot, immersed in surrounding whirls and thousand mile-long eddies, was more vivid than anything Stanley Kubrick had imagined in *2001: A Space Odyssey.*

Saturn's rings, long so distinctive through the telescope, now were almost close enough to touch. Most unusual of all was a "braided ring" that looked like a gargantuan strand of DNA.

These past moments of planetary drama will be matched, and probably surpassed, in coming years. The new golden age still has far to run, for many of its maps are incomplete. And Bruce Murray's call–to "look for the first time at new worlds"– continues to define the work for today's space explorers.

–T.A. Heppenheimer

In March 2003, the European Huygens probe will be deployed from the Saturn-orbiting Cassini spacecraft to drop down into Titan's thick orange haze, photographing the surface as it descends.

to stay."

So NASA is making plans as if he actually meant it. Not all our scientific questions about the Moon were answered in the 1960s—far from it. Nearly every national space agency in the world, and at least one private group, has some kind of lunar polar orbiter mission on its wish list, to produce a global map showing the distribution of minerals on the Moon and to more fully understand its surface properties.

The U.S. entry in this Moon derby is the **Lunar Observer,** now planned for launch in 1997 (if approved as a new mission by Congress in 1992.) The timetable might even move up, depending on the seriousness of the Bush Moon/Mars initiative.

The Lunar Observer is not a complicated mission, and its scientific rationale has been outlined since the early 1970s. A single spacecraft will first be placed in an elliptical orbit over the lunar poles, passing low enough to map the Moon's gravity field very accurately. The orbit will then be circularized and raised to an altitude of about sixty miles, at which point the one-year main mission begins.

Onboard the spacecraft will be gamma ray and x-ray spectrometers for chemical analysis of the Moon's surface, a laser altimeter to map the terrain, a camera and visible light/infrared mapping spectrometer, and instruments to measure heat, gravity and magnetic fields. Those instruments will inventory the Moon's titanium, aluminum and other resources (possibly even water, if it exists), and take its vital measurements.

Not least importantly, Lunar Observer's high-quality photographic maps (with a resolution better than 30 feet for more than half the Moon) will help in selecting a site for a future human outpost.

The Lunar Observer probably won't be the only spacecraft to visit the Moon before the humans return. **Galileo** will make lunar observations during both of its Earth flybys (in 1990 and 1992) before heading off to Jupiter, and the independent Space Studies Institute is currently trying to muster the resources for a very modest, single-focus, privately funded **Lunar Prospector** mission to search for water at the lunar poles (see page 16).

A lunar orbiter also has its advocates in the Soviet space science establishment, but there is as yet no officially announced mission. The Japanese, meanwhile, have expressed interest in sending a series of seismic penetrators to the lunar surface, perhaps in conjunction with a future American mission. That could improve our knowledge of the lunar soil and bedrock before the construction crews show up.

Mars

Like the Moon, Mars has now been officially declared a goal for future human exploration. What used to be a purely scientific agenda, therefore, is now geared toward sending precursor missions that will pave the way for the first astronauts and cosmonauts.

At present, there is only one fully funded U.S. Mars mission, the **Mars Observer,** with a planned launch date of September 16, 1992. After a cruise of nearly a year, the spacecraft will arrive at Mars in August 1993 to observe the planet for one Mars year (two Earth years), from a nearly polar orbit only 210 to 240 miles above the surface.

Whereas earlier Mariners and Vikings followed wide, elliptical paths around Mars that took anywhere from 12 (Mariner) to 24 hours (Viking) to complete one orbit, the Mars Observer will be placed in an up-close-and-personal, two-hour circular orbit. From that close range it will map the mineralogical composition of the surface, take photographs, assess the gravity and magnetic fields and begin building a database on seasonal variations in the Martian weather. Scientists are hoping for nothing less than a "global understanding" of Mars.

The NASA spacecraft is planned to still be in orbit at the time of the planned Soviet Mars 1994 mission. So, in the spirit of international cooperation as well as enhanced scientific return, it will carry a French-built Mars Balloon

The other worlds of the outer Solar System—Jupiter, Uranus, Neptune and Pluto—may have to wait until nuclear electric propulsion engines are developed before spacecraft are able to land on their icy moons.

Relay along with its regular complement of instruments.

As part of the Mars 1994 mission, the French balloon experiment is expected to fly in the Martian atmosphere for about ten days in autumn 1995 (*Final Frontier,* August 1988), landing in a different place each night. A TV camera in the balloon's gondola will beam pictures up to both the Soviet orbiter and the Mars Observer, which will relay the transmissions back to Earth.

Of all the planned Soviet planetary missions, **Mars 1994** seems to be on the firmest budgetary footing, even though the size and scale of the mission have recently been cut back. Launch is planned for October 1994, with arrival at Mars the following September. Current blueprints call for an orbiter and an atmospheric entry module (a smaller one than previously planned), along with a single French-built balloon (reduced from two) that will take pictures of the surface and make direct measurements when the balloon is in contact with the ground. This "Mars Aerostat," as the balloon experiment is called, is now in the detailed study phase, and scientists all over the world are contributing data on the Mars environment.

The orbiter will carry infrared and ultraviolet spectrometers among its suite of instruments, along with a German/Italian/Soviet camera system that will take high-resolution stereo pictures of the whole planet during the lowest part of each 12-hour, elliptical polar orbit.

The Soviets are planning to use a modified (and hopefully more reliable) version of the twin spacecraft that failed to reach the Martian moon Phobos earlier this year. Speaking of which, the possibility of a future Phobos sample return mission has been raised recently by Soviet officials, and NASA also is looking at the Martian moons as possible targets for one of the agency's new low-cost, "Discovery" planetary missions.

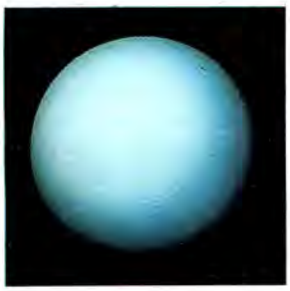
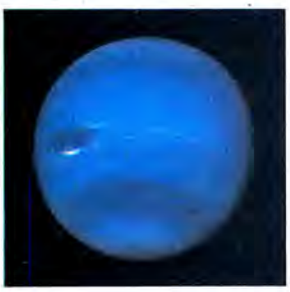
The next major push in NASA's Mars strategy, however, is likely to be the establishment of an international **Mars Network**. Sometime after the Mars Observer but before a sample return mission— meaning either in 1996 or 1998, depending on the pace of the Bush Mars initiative—one or more spacecraft would deliver a number of ground stations to the surface of Mars to measure volcanic activity and Marsquakes, monitor the Martian weather, search for water and take other physical and chemical readings that would be of interest to those planning future robotic and human expeditions.

The sequence of events, and even the participants in setting up such a network, are far from decided. The seismometers could be placed on landers, or could be dropped to the surface inside penetrators deployed from orbit. A seismic network requires at least three stations at different locations, but if low-cost penetrators are used, there could be as many as 24. The network could be set up all it once, or in stages.

Meanwhile, plans for the **Mars Rover Sample Return** that probably will follow the network are proceeding. As many as 100 NASA employees and contractors are now working on conceptual designs for what are actually two vehicles: a rover that would wander anywhere from 100 yards to a hundred miles or more from the landing site; and a sample return mission that would return a few pounds of Martian rock and dirt to Earth.

Again, uncertainties about cost and about which nations will be participating affect the plans. If the Soviets or

continued on page 48


The show from Neptune was everything you'd expect from one of history's great explorers.

FAREWELL, VOYAGER

When it was all over, as Voyager 2 headed into the interstellar night, I went to get a look at Neptune for myself. After you've had your mind expanded, you need to hold onto something solid and take a step back. I wanted to see the eighth planet the way it had been before, when no one had heard of a Great Dark Spot, or a pink moon, or ice volcanoes.

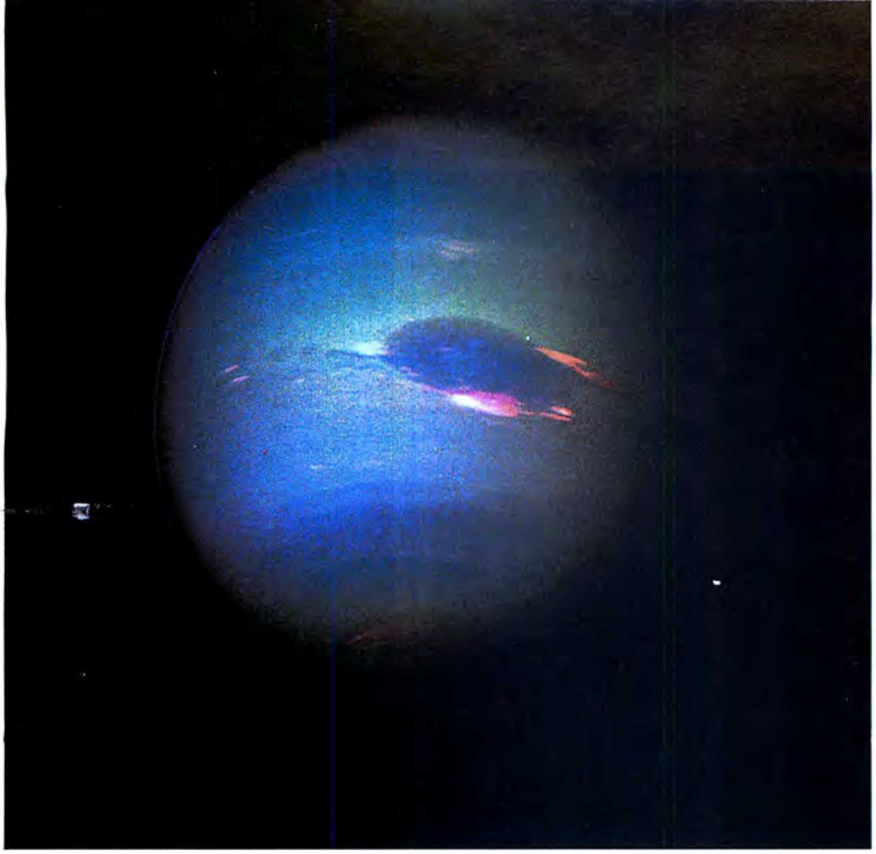
It was up in Sagittarius, not far from where Saturn gleamed like a jewel in the evening sky. Neptune is invisible to the naked eye, so I went to the nine-inch refractor at Harvard College Observatory. After some careful star-hopping, there it was: a tiny bluish dot, decidedly unimpressive, seemingly as remote as the stars. At 2.8 billion miles, it is currently the farthest planet from the Sun, an honor that it has temporarily usurped from wandering Pluto until 1999.

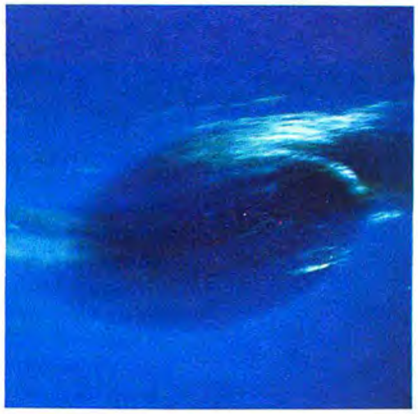
I had seen Neptune like this once before, during a rare alignment in 1982, when it was possible, with some care, to glimpse all nine planets in one predawn observing session. That same once-in-a-lifetime lineup had made it possible for Voyager 2 to compress a journey of more than four billion miles into a mere 12 years. Neptune was just the last stop on a journey that had already transformed planetary exploration.

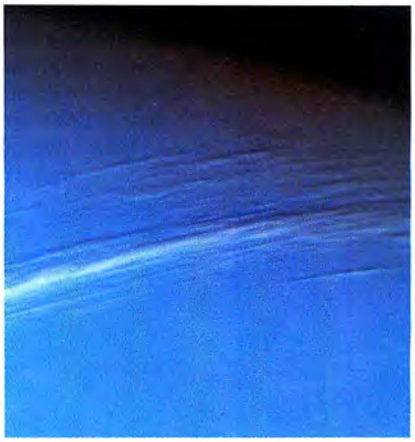
At Jupiter we had seen an atmosphere churning with activity, banded with variegated clouds and swirling cyclones that dwarf any on Earth. Jupiter's family of moons was a solar system in miniature, including Europa, an ice world as smooth as a billiard ball, and Io, a world of rock and sulfur literally turning itself inside out with volcanic activity. Saturn, in all its ringed splendor, was a feast for the eye and a challenge to the imagination. Voyager revealed the rings to be not a continuous sheet of particles, but a collection of ringlets, more numerous than anyone could count, that seemed to defy physics: Rings that braided around each other, rings that had clumps, kinked rings.

In January 1986, Uranus appeared out of the blackness, rolling on its side, a nearly featureless blue-green ball. On the face of its satellite Miranda we saw the most bizarre checkerboard of terrain imaginable. Each time we thought we had seen it all, a stranger world showed us we'd been wrong. We marked our calendars for August 24, 1989, certain that Neptune would not

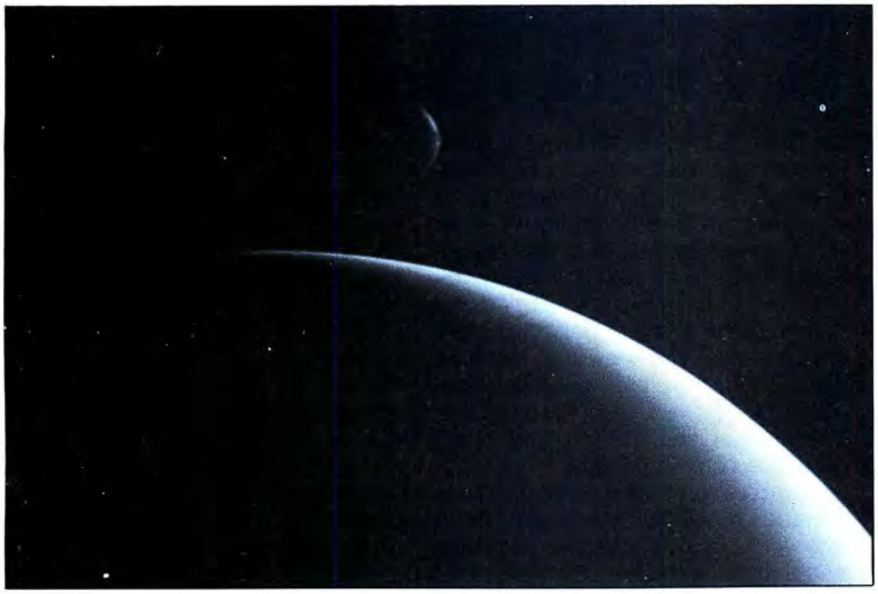
BY ANDREW CHAIKIN







ALL PHOTOS: NASA/JPL



Clockwise from upper left: false color image of Neptune; the Great Dark Spot; a close-up view of clouds and shadows; and a parting-shot double crescent of Neptune and Triton.

disappoint us.

Practically everyone with access to NASA's satellite TV link was poised on that night to watch Voyager's encounter with Neptune live, right along with the scientists and engineers who directed the mission. It was a full-fledged Event, exploration for Everyman. In Pasadena, home of the Jet Propulsion Laboratory—mission control for Voyager—a Planetfest at a nearby convention center drew thousands of enthusiastic spectators. Across the country science museums, schools, universities and planetariums hosted encounter watch-ins. Public broadcasting went on the air with "Neptune All Night," and drew more than two million viewers.

I tuned in to NASA's Voyager downlink at the Regional Planetary Data Center at Brown University in Providence, Rhode Island. Twelve years ago, when the spacecraft was beginning its journey, I was an undergraduate geology major there. Like so many others who followed Voyager's long strange trip, it seemed to me that these 12 years had brought as many changes to the watchers as to our knowledge of the Solar System. On the evening of August 24, armed with lots of coffee, I joined a few of the watchers, graduate students in planetary geology, and hunkered down for a night of discovery.

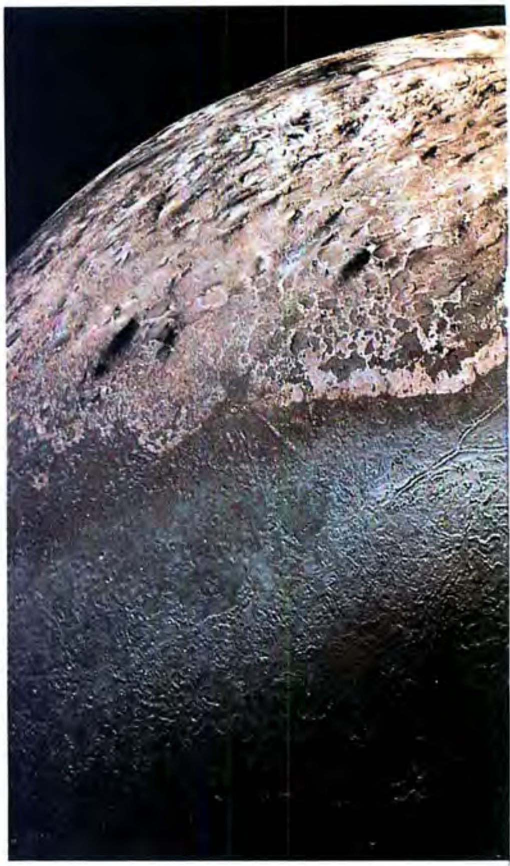
Thursday, August 24
8:00 p.m., Eastern Daylight Time

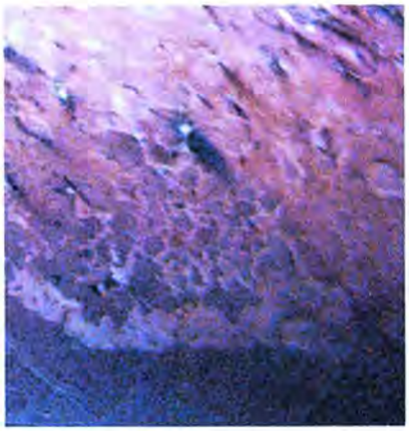
Here is how the flyby will go: Voyager, falling ever faster toward Neptune, will skim less than 3,000 miles above the planet's north pole. Its aim is calculated precisely so that Neptune's gravity will bend the spacecraft's path just the right amount to send it on to a close flyby of Triton.

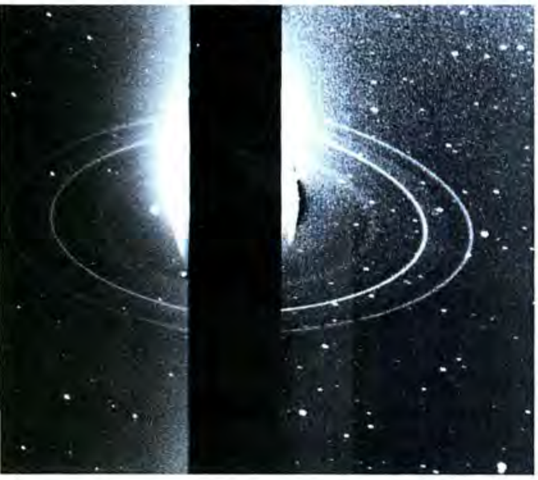
In all the astronomy books I grew up with, Neptune was always lumped in with Uranus. Both gas giants, about four times the size of Earth. Both mostly hydrogen and helium, laced with methane and ammonia. Possible core of rock and ice deep beneath the thick atmosphere. There was one obvious difference: Uranus rotates on its side, while Neptune's spin axis points more nearly north-south.

But there wasn't much else to say, mostly because both planets are so far away that even with the largest telescopes astronomers could glean little from their dim light. Only in the last few years, working with ever more sensitive detectors such as charge-coupled-device (CCD) cameras, had they

Triton (shown here and at far right in a mosaic of a dozen Voyager photos) proved as fascinating as scientists had hoped it would be, from its pink, icy polar cap to its grooved "canteloupe terrain." Right: close-up views of the moon's surface showed dark streaks that may be wind-blown volcanic material.







From arcs to rings: Voyager's cameras took nearly ten minutes to expose two images (above) proving that there are, in fact, continuous rings around the planet. High-resolution images showed distinct rings as well as a faint sheet of more diffuse material.

begun to lift the veil. Observers found that Neptune, unlike Uranus, was emitting twice as much energy as it receives from the Sun. Infrared images, though fuzzy, confirmed the atmosphere was stirring with activity: Broad bands of light and dark girdled the planet. By the time Voyager arrived, scientists pretty well knew that Neptune would not be the bland, featureless ball that Uranus was. But no one anticipated the planet that has for the past week filled our TV screens.

Voyager's Neptune is a beautiful blue banded globe, laced here and there with white cirrus clouds, positively photogenic, a tastefully understated version of Jupiter. There are even two large, dark ovals resembling Jupiter's Great Red Spot, thought to be a gigantic cyclone at least 300 years old. Voyager scientists, Jupiter buffs one and all, have christened the larger of the two the "Great Dark Spot."

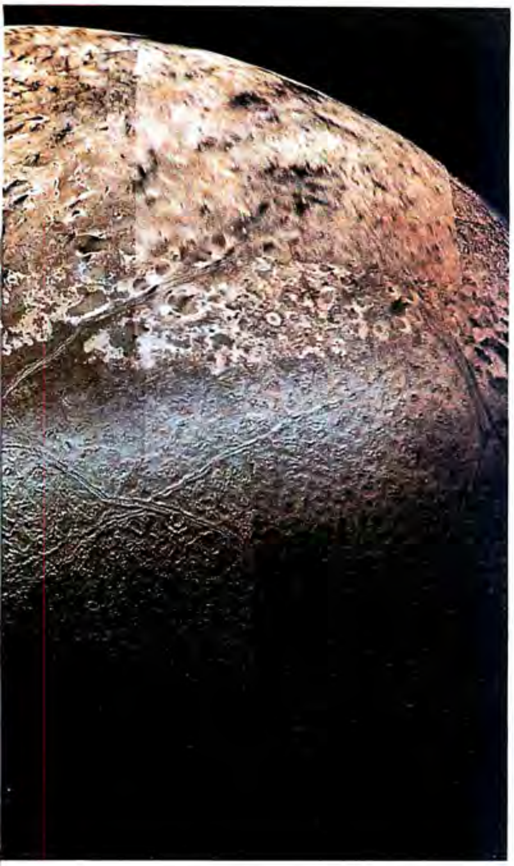
On the way to its close flyby, Voyager also has confirmed something else scientists had anticipated: Neptune, like Jupiter, Saturn and Uranus, is encircled by a set of rings. Earth-based observations had suggested the rings might go only part way around the planet, which would have posed quite a puzzle to physicists. The Voyager images show that they are, in fact, complete rings. Like the rings around Uranus, they are narrow and very dark.

In its three previous planetary encounters, Voyager never failed to discover new worlds, and Neptune is no exception. During the approach it has found six previously unknown satellites, including a dark, battered moon some 240 miles across, Neptune's moon Nereid, discovered in 1948. The "new" satellite had gone undetected because it orbits too close to the planet for Earth-based telescopes to pick it out of Neptune's glare. Some day it will have a name, probably drawn from mythology. For now, it's given the uninspiring designation "1989N1."

The hours surrounding the closest flyby will be packed with data. Some will be stored on tape and played back later, but much of it will come down live. By the time Voyager's signals cross the nearly three billion-mile gulf between Neptune and Earth, they are so faint that a network of huge antennas around the world, acting in concert, is required to pick them out of the background of radio "noise." Simply receiving Voyager's data is a triumph.

11:00 p.m.

Voyager is so close to Neptune that the Great Dark Spot nearly fills the TV monitor. Streamers of white clouds, suspended above the huge dark oval,



trace its curved edge. In a live update from JPL's TV studio, Voyager scientist Andy Ingersoll of Cal Tech is reduced to such unscientific utterances as, "Wow, it's really a great planet."

By now, with three other planets under their belts, Voyager scientists expect to discover things they had not anticipated. That remarkable ability—anticipated serendipity—has led project planners to sprinkle among the carefully programmed sequence of pictures a number of "retargetables," images that could be re-pointed with relatively little advance notice. The planning has paid off with views like this one.

The picture is the result of superb aim and crafty weather forecasting. In order to program Voyager's computer in time, scientists had to predict 11 days in advance where the swirling storm would be at the moment the picture was made. It is the best image scientists will get of the Great Dark Spot; closer in, Voyager will be moving too fast to take a clear picture of it.

As bountiful as the encounter is, there are frustrations for Ingersoll and the other scientists studying Neptune's atmosphere. He explains that the Great Dark Spot is one of only a handful of Neptune cloud features that they can identify from one image to the next. Normally they would measure the speed of Neptune's winds by tracking the motion of clouds in successive images, but with few such markers available, the scientists find their work difficult. And, although some of the most telling data about Neptune, from Voyager's other sensors, is yet to come, Ingersoll and the other atmosphere scientists will have to make do with the pictures they already have.

Faced with leaving Neptune with a head full of unanswered questions, Ingersoll confesses that if he could "take control of the spacecraft, and not have to share it with the geologists," he would keep Voyager's cameras trained on Neptune's clouds, in hopes of capturing their motion. But Ingersoll knows better; some of the most exciting images, the closeups of Triton, are the ones the Voyager scientists are most eagerly awaiting.

11:56 p.m.

Right now, the spacecraft is making its closest approach to Neptune, passing just 3,117 miles above the north polar clouds, whizzing past at 61,000 miles per hour. One of the paradoxes of the encounter is that we experience events not at the time they occur, but at their "Earth received time," four hours and six minutes later. Everything we see has already happened long ago. The data from this closest approach will not arrive until early tomorrow morning.

The last half-day has produced some of the most astonishing data of the encounter. Nine hours before closest approach Voyager entered Neptune's magnetosphere, the region of space dominated by the planet's magnetic field. Neptune's field is not strong—one scientist calls it "rather humble." But it is remarkable, nonetheless: The magnetic poles are offset by some 50 degrees from the planet's axis of rotation.

Magnetically, Neptune is surprisingly like lopsided Uranus, despite the other apparent differences between the two worlds. It is a mystery that scientists will ponder long after the encounter is over.

August 25, 1:00 a.m.

Ring specialists Rich Terrile and Jeff Cuzzi are examining a new close-up of one of Neptune's rings. The ring looks deceptively simple, a bright line crossing the field of view. In reality it is made of innumerable particles of ice and dust, each one a separate satellite of Neptune, moving in accordance with the complex laws of orbital mechanics.

Left to their own devices, the ring particles would have long ago spread into a single, uniform sheet, but they remain confined to a handful of narrow bands. This is familiar to Terrile and Cuzzi. They've seen the same thing at Jupiter, Saturn and Uranus. To the scientists, this is evidence that a host of small moons, as yet undetected by Voyager's cameras, orbit near the rings, and perhaps within them. The gravitational influence of these "shepherding" moons keeps the circling material confined as rings.

On the new image, Cuzzi finds still more evidence for unseen moons within the rings: The ring is not uniform, but contains clumps of material. This kind of detective work is the ring specialists' stock-in-trade, and they've learned to make do with theory when hard evidence is lacking. By the end of the encounter, a handful of ring-moons will be found, but not nearly as many as the scientists would like.

Voyager's dark and cratered new moon, "1989N1."

1:53 a.m.

An incredible, beautiful image appears, one of the last of Neptune before closest approach. It shows a collection of bright cirrus clouds, like jet contrails side by side, casting shadows on the vast cloud deck below. Suddenly, an extraordinary intimacy with Neptune: We are close enough to see shadows on a world at the edge of the Solar System.

Our attention turns to the hazard of the ring plane crossing, as these data are about to come in. Voyager has braved hazards along the way—Jupiter's fierce radiation belts, Saturn's rings. Now it will run Neptune's ring gauntlet. While the Neptunian rings are far less substantial than Saturn's, there is still risk, for at Voyager's speed of nine miles a second, a single particle the size of a grain of sand could do terrible damage.

We see the readout of the spacecraft's Plasma Wave experiment, which doubles as a dust detector. The hits

continued on page 52

If you think Voyager's quick flyby of Jupiter was spectacular, get ready for a full-fledged expedition.

ENTER GALILEO

Call me Galileo. I'm free now from the restraining grasp of Atlantis. Even as I watch the shuttle retreat to a safe distance, I know the crew is methodically counting down to my departure.

"Three...two...one...Ignition!"

My booster erupts with a thump that shakes me through to my titanium skeleton. Behind me is a flickering peacock tail of fire. Finally, long after the spaceship disappears from sight, the Earth begins to grow visibly smaller. I glimpse a bright pinpoint of light, far beyond the receding blue planet—my ultimate destination.

How long does it take to get to Jupiter? That depends on whom you ask. A direct flight to the planet might only take eighteen months or so. The more leisurely itinerary of Galileo will require some six years. And for those who've been working to get the mission launched, it's been twice that long already.

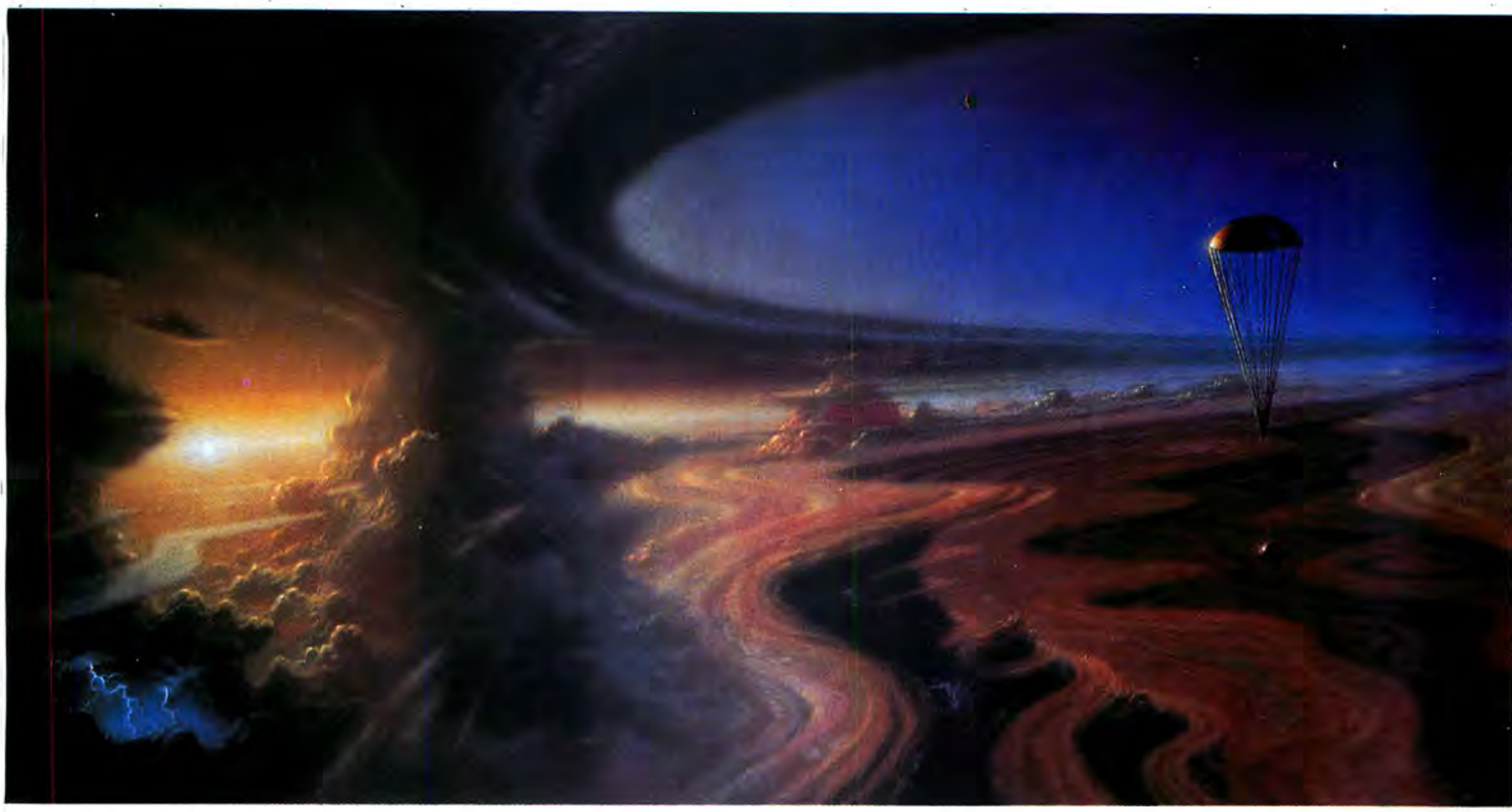
Ever since the spacecraft's namesake discovered in the 17th century that Jupiter *was* a planet (and in the process forever changed the meaning of that word from "wandering star" to "world"), it has been rivalled only by Mars and Venus as a favorite stop on any tour of the Solar System.

Long before the Space Age, there were visionaries who dreamed of travelling beyond the Earth, and many of the earliest speculative voyages chose Jupiter as their destination. In Jules Verne's 1877 novel, *Hector Servadac,* a wayward asteroid carries a group of hapless humans through the Solar System, making a close approach to Jupiter before its cometary orbit returns its passengers to Earth. The anti-gravity spaceship "Callisto" made the trek voluntarily in the 1894 saga *A Journey in Other Worlds* by John Jacob Astor (yes, *that* Astor). So too did the "Astronef" in George Griffith's *Honeymoon in Space* (1900).

The authors tried to describe conditions on Jupiter, but the limitations of late 19th-century science fettered their accuracy. Griffith's honeymooners, for example, saw "vast continents shape themselves and melt away into oceans of flames, while mountain ranges of flowing lava were hurled up miles high to take shape for an instant and then fall away again, leaving fathomless gulfs of fiery mist in their place."

As science progressed in the twentieth century, Jupiter grew more poisonous, colder and more hostile. Its

BY RON MILLER



ALAN GUTIERREZ

December 1995: Galileo's probe meets Jupiter's stormy atmosphere.

sheer strangeness made it a prime target for the space missions that bold designers began planning as early as 1961. After several false starts— missions using nuclear rockets and the mammoth Saturn 5 Moon rocket once were considered—the scaled-down Pioneer 10 and 11 spacecraft went winging off to the Jovian system for a quick look-see in the early 70s, followed by the now legendary Voyagers in 1977.

But those missions were relatively simple flybys, rather like watching the passing scenery from a train without stopping to explore the countryside. In 1968, even before the Pioneer flights, the Astrosciences Center of the Illinois Institute of Technology had done the first serious studies of Jovian entry probes. The Jet Propulsion Laboratory (JPL) and NASA's Ames Research Center, meanwhile, conducted their own investigations through the mid-70s.

Early 1976 saw the birth of the Jupiter Orbiter-Probe, a concept that combined a spacecraft to orbit the gaseous giant with an entry vehicle to hurtle into its turbulent atmosphere. JPL and Ames formed a team, the former to manage the entry probe and the latter to build the orbiter.

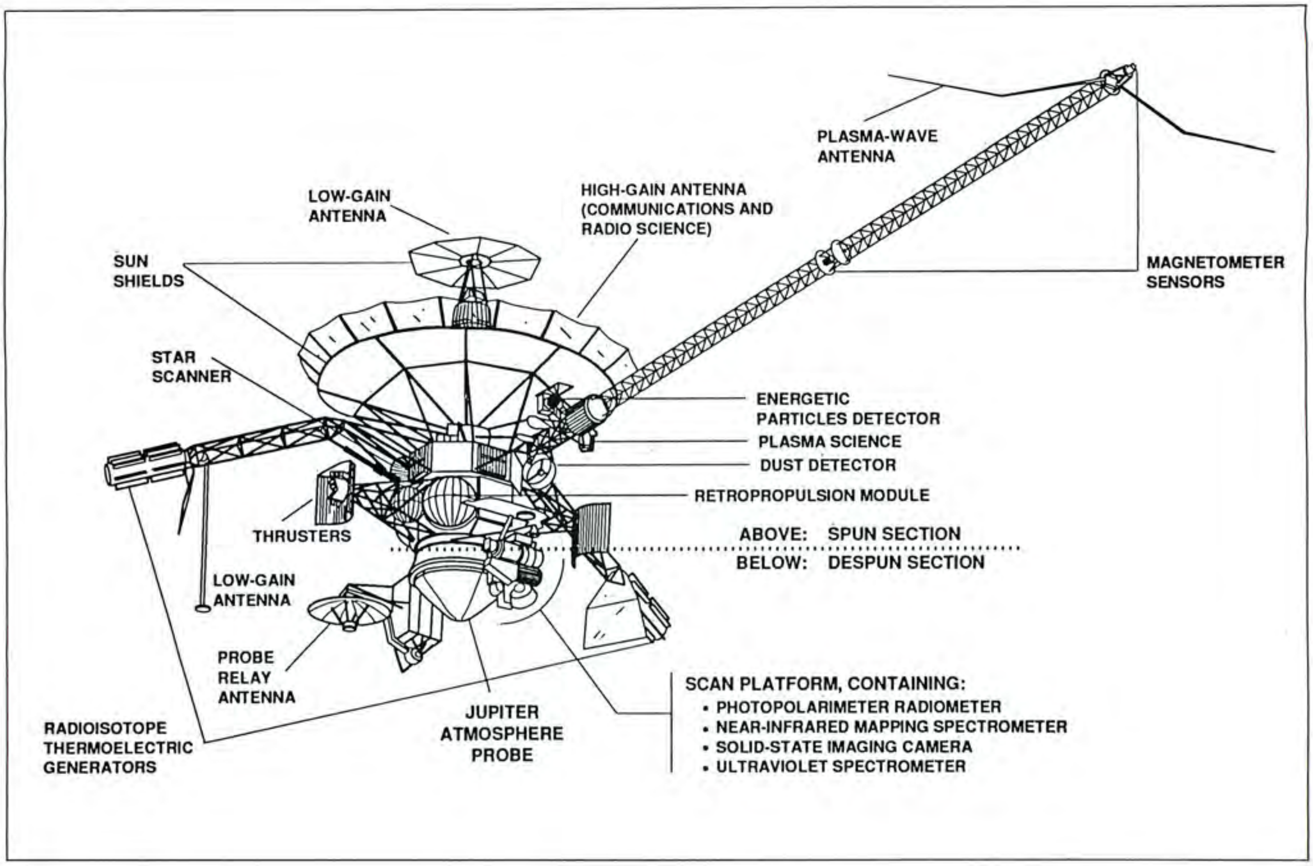
With formal Congressional approval in 1979, the mission got a new name: Galileo. It was scheduled to be launched in January 1982 on the thirtieth flight of the space shuttle, but delays in the shuttle program moved Galileo back again and again. Finally the Challenger disaster put a double whammy on the mission. The spacecraft had to sit in storage until shuttle flights resumed; expendable launch vehicles capable of a Jupiter mission simply no longer existed. And shuttle managers decided that the liquid-hydrogen Centaur booster that was to have sent it beyond Earth orbit was too dangerous. It was replaced by the safer but less powerful two-step Inertial Upper Stage (IUS).

There was one small problem: IUS lacked the requisite oomph to boost Galileo directly to Jupiter, and a way had to be found to make up the difference in energy. Mission designers discovered "VEEGA," the Venus-Earth-Earth-Gravity-Assist trajectory—thereby turning what had been a straightforward planetary mission into a sort of "mini-grand tour" of the Solar System out to Jupiter.

Galileo is the most complex mission ever sent into deep space. The spacecraft itself is a technological breakthrough:The orbiter's upper section, with instruments to detect magnetic fields and charged particles, spins slowly, while the lower part, including a scan platform for cameras and spectrometers, remains stationary. Altogether, there are ten scientific instruments on the orbiter, with another six on the teardrop-shaped probe that will be dropped into Jupiter's atmosphere.

After years of waiting in clean rooms and holding facilities, Galileo will finally get off the ground in mid-October, on shuttle flight STS-34. Five months after its launch from Atlantis, the spacecraft is scheduled to reach Venus, streaking over the morning terminator (the shadow line between night and day) at an altitude of 9,000 miles. Taking advantage of a close approach to the cloudy world, Galileo will search for evidence of lightning in the atmosphere as well as determine its composition and distribution with infrared spectroscopy.

The Venus flyby wasn't considered in the original design of the spacecraft. Sunshades were added to protect Galileo's delicate electronics compartments, science boom, magnetometer and so forth. Since the high- and low-gain communication antennas will both be aimed away from the Earth for the first few hundred days of the voyage, a third, aft-pointing antenna also was added.



"Fields and particles" sensors mounted on long booms and fixed to the main spacecraft body will study the violent, radioactive environment near Jupiter's volcanic moon Io.

After leaving Venus, Galileo will be travelling a little faster, like a stone whipped from a sling—the whole purpose in sending it there in the first place—and on course for a brief visit to the Earth and its Moon. In the ten-month interval before returning home, Galileo will continue to make itself useful, its ultraviolet instruments searching for evidence of neutral hydrogen atoms in the inner Solar System, which may be the relics of vaporized comets that, according to one theory, are still raining down on Earth.

In December 1990, Galileo will become the first planetary spacecraft to complete a round-trip to Earth. Approaching from the night side, the robot explorer will rocket over our terminator at an altitude of only 600 miles. During this pass it will dump the data it collected at Venus; because the spacecraft can't use its high-gain antenna so close to the Sun, all of the data will have been recorded for playback.

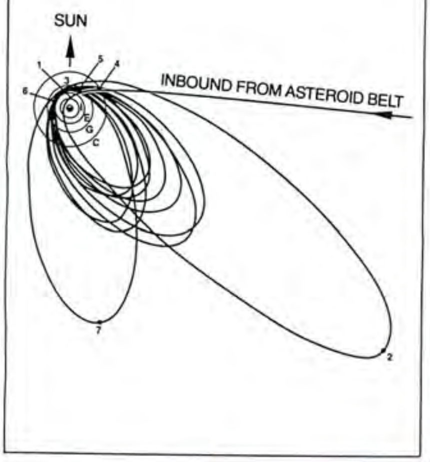
Like a steel ball in some cosmic pinball machine, Galileo will be shot by Earth's gravity into a wider solar orbit. For the next two years, it will cruise the inner Solar System, measuring concentrations of interplanetary dust and studying ultraviolet emissions.

There will be some Voyager-class drama as well. A little more than two years after launch, Galileo will zoom by the asteroid Gaspra. From 600 miles away, the spacecraft will concentrate on the basics: surface composition, rotation rate and, of course, lots of tourist snapshots. Images of Gaspra should have a resolution superior to those of Uranus' moon Miranda sent back by Voyager 2 in 1986.

Galileo's second gravity assist from Earth, in December 1992, is the one that has trajectory planners chewing their calculators. The spacecraft will hurtle around the home planet less than 200 miles above the surface, picking up enough speed to send it off on a six-year orbit around the Sun that will intersect Jupiter's orbit in 1995.

Before the launch, anti-nuke activists made this scheduled close encounter a *cause celebre*. ("Chernobyl In The Sky!!!" screamed one handout.) They dutifully noted that Galileo carries something like 50 pounds of plutonium in its radioisotope thermoelectric generator (RTG) batteries, and a slight *oops* could cause the stuff to rain down into the atmosphere. Despite the precision that NASA has demonstrated in threading planetary needles with spacecraft at billion-mile distances, it's unlikely the issue will die until Galileo is safely on its beeline to Jupiter.

On the way out, Galileo will visit one more asteroid, Ida, in August 1993. The



Galileo will travel an ever-shifting series of loops that brings it near at least one of Jupiter's large moons—Io, Europa, Ganymede or Callisto—on each orbit. Below: Project engineers have waited years to get their spacecraft off the ground.

same distance it encountered Gaspra, but it will be whizzing past much faster, about eight miles per second. Scientists hope Ida's size—roughly twice the size of the first asteroid—will make the flyby just as rewarding.

About six months before arriving at Jupiter, in early July 1995, Galileo will separate into two parts: The probe will continue independently toward its entry into the violent atmosphere, while the orbiter performs a trajectory correction that will cause it to overfly the probe and eventually go into orbit around the giant planet.

The first-act finale of Galileo's space ballet begins on December 7, 1995, when the orbiter is scheduled to pass the pizza-faced moon Io, with its sulfurous volcanic fountains and lava flows. The speeding spacecraft will train its near-infrared and ultraviolet spectrometers on Io to improve our knowledge of the satellite's chemical makeup, and do as much other science as the quick encounter permits.

The real stunner at Io should be the close-up images shot during the flyby. The miss distance, 620 miles, is calculated to help Galileo slow down before the spacecraft fires its German-built retrorocket to enter a looping circuit around the Jovian system. But it's also about 20 times closer than Voyager 1's encounter in 1979—and Galileo's high-resolution camera is a *hundred* times more sensitive. One handy analogy is that we'd be able to see the individual buildings in any theoretical Ionian cities, whereas at Voyager's resolution we'd only have suspected that the cities themselves existed.

Shortly after the orbiter's brush with Io, the anxious scientists at JPL will shift their attention to the highlight of the Galileo mission: entry of the probe into Jupiter's atmosphere. The 800-pound craft will penetrate not far north of the Jovian equator, at about the equivalent latitude of Sri Lanka on the Earth. Travelling at 100,000 mph, it will hit the atmosphere like a meteor, a blinding fireball streaking across the livid sky. Four hundred g's of deceleration will slow it enough to deploy a parachute, and the instrument module will finally begin to relay measurements to the orbiter passing overhead.

The probe will attempt an ambitious program of scientific investigations as it sinks through its hostile surroundings. Its key instrument is a compact neutral mass spectrometer that should let researchers precisely determine the composition of Jupiter's atmospheric gases. Also onboard are experiments to chart atmospheric structure, the location of cloud layers and characteristics of cloud particles.

Some of the data the probe will obtain has implications beyond Jupiter itself. The ratio of hydrogen to helium in the Jovian atmosphere is important to astrophysicists, because many believe Jupiter's composition mimics the primordial solar nebula from which our Sun and planets formed. Measurements by the net flux radiometer, which will observe atmospheric changes visible only in infrared wavelengths, may tell us more about the basic driving forces behind the planet's complex weather systems.

The fragile bundle of instruments will swing beneath its parachute, buffeted by hurricane-force winds and methane and ammonia hail. Lurid clouds will most likely be rushing past as if in a time-lapse film, illuminated by lightning bolts large enough to incinerate an entire terrestrial city. Finally, at a depth where the atmospheric pressure is about 20 times the sea level pressure on Earth, temperature and weakening radio signals to the orbiter will silence the probe. It will all be over with an electronic whimper—only an hour after the drama began.

Not for the Galileo orbiter, of course. The busy spacecraft will have settled in for at least a 22-month mission, during which it will circle Jupiter ten times and have a close encounter with at least one Jovian satellite on every orbit.

Although Galileo's main body spins for stabilization at nearly 3 rpm, the cameras and some other experiments are on a "despun" platform so they can remain pointed at their targets. Among the instruments Galileo will be training on Jupiter will be a near-infrared mapping spectrometer, an ultraviolet spectrometer, a magnetometer and radio science experiments. One hundred and fourteen scientists from six nations will be awaiting Galileo's broadcasts.

The orbiter's first circuit after passing Io is its longest: It will be another 150 days before the craft re-enters the realm of the Planet King. At the apogee of the long, elliptical orbit, Galileo will fire a burst from its rocket engine to retarget itself toward a second Jovian moon, probably Ganymede. During each subsequent "tour" of the planetary system, the robot will adjust its trajectory using its engine and gravity assists from the satellites it visits.

Just as at Io, the views of icy smooth Europa, scarred Ganymede and cratered Callisto should be striking. Galileo's imaging system will provide pictures 20 to 100 times superior to any obtained before; we should see details down to 100 feet across on some satellites. And the ability to adjust Galileo's orbit means that the spacecraft can inspect the polar regions of the moons for the first time.

Moons, though, aren't the only reason Galileo will take a different track on every tour. As it loops round and round, the orbiter will be changing its orientation to Jupiter's atmosphere and mapping out a path through the gaseous giant's magnetic field, or "magnetosphere." The Voyagers discovered that the Jovian magnetosphere is very dynamic, churning with energies far exceeding those of Earth's van Allen belts. It's also chock full of energized particles originating from the planet and its satellites—Io alone pumps about a metric ton of oxygen and sulphur atoms into the magnetic field each *second* .

The ability to study this environment

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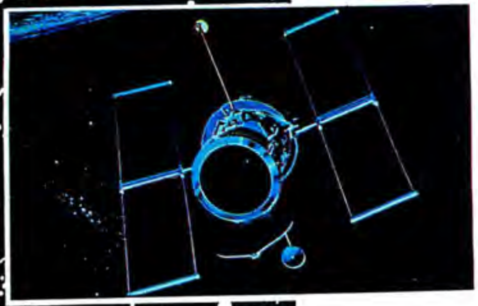
New Worlds



NASA's long-awaited space telescope will explore the Solar System without ever leaving Earth orbit.

NEIGHBORHOOD WATCH

The Hubble Space Telescope, due to be launched next March, will be the most advanced instrument ever made for observing the most distant objects in the Universe. But the sensitive instruments tucked just behind the telescope's 94.5-inch primary mirror also will be of great value to planetary astronomers. The telescope's Wide Field/Planetary Camera, for example, can be used to hunt for wayward asteroids, while the Faint Object Camera will be ideal for observing dim comets or planetary atmospheres. Along with three other onboard instruments, they will have plenty of work observing comets, asteroids, planets, ring systems and moons in both visible and ultraviolet light.

Why use an Earth-orbiting telescope when we can send spacecraft to visit nearby planets? "Spacecraft give us snapshots, not long-term observations," says Harold A. Weaver, Associate Astronomer at the Space Telescope Science Institute (STScI), the Baltimore-based center responsible for the planning, support and handling of the telescope. "We know weather on the Earth changes dramatically from day to day. On the outer planets, we have the same thing."

Another reason for conducting Solar System observations with Hubble is the telescope's size and versatility. "You can't send a large, heavy spectrograph to a planet on a small spacecraft—but you can put it into a space-based observatory," says Robert A. Brown, a planetary astronomer at STScI. In addition, he says, "It's easy to fix or upgrade the instruments in Earth orbit, but once you send a craft to Pluto, you're stuck with what you thought was smart 17 years before."

Observations planned for the first seven months of Hubble's life in orbit will address a broad cross-section of planetary problems such as the origins of comets and asteroids, the precise orbits of newfound planetary satellites and the study of planetary rings and atmospheres. All of the known planets are fair game, excluding Mercury, which is too close to the Sun to risk Hubble's delicate optics.

Ultraviolet observations will be among Hubble's most valuable Solar System experiments. "We are always looking at the lighted side of the planet with [the telescope], making it difficult to see such phenomena as auroras," says Francesco Paresce, an astronomer at STScI who is one of the first observers with guaranteed time on the telescope. "But the Sun 'turns off' in the UV, so there

BY PATRICIA BARNES-SVARNEY

The Voyager and Viking spacecraft had to travel millions of miles to achieve this kind of detail in their close-up planetary photos. From Hubble's vantage point above the atmosphere, the space telescope will routinely be able to match the resolutions shown here for Jupiter, Saturn and Mars.

is no scattering of light—only what is transmitted by the planet."

Of the 162 proposals picked recently to receive viewing time on the telescope, 20 involve planetary targets. Cometary studies topped the accepted list, with Jupiter, Pluto and its moon Charon running close behind.

The planetary "missions" cover a wide range of science. John Clark of the University of Michigan will conduct a direct search for auroral-type phenomena on those outer Solar System satellites like Saturn's Titan that have atmospheres. Rita Beebe of New Mexico State University has proposed a monitoring program to study short-term changes in Jupiter's atmosphere. And Benjamin Zellner, an astronomer at Computer Sciences Corporation, hopes to determine the composition of the Martian moons Phobos and Deimos, which may in fact be asteroids captured by the gravitational pull of the Red Planet.

Not all the proposals will be assigned a firm slot on Hubble's viewing schedule. For example, one of Harold Weaver's two proposals is to observe "new" comets. Unlike the periodic comets such as Halley whose orbits are well documented, new comets have made no previous appearance in our neighborhood. Since these visitors are by definition unpredictable, Weaver's proposal comes under the "target of opportunity" program. If a new comet is discovered with a ground-based scope, Hubble observations will be wedged into the schedule.

Zellner also has a "target of opportunity" observation using the Wide Field/Planetary camera. Images of galaxies and other deep space objects will be checked for signs of much smaller objects close to home. "We are looking for short trails that will represent unknown comets or asteroids—objects that are way out in the Solar System," says Zellner. If such distant objects appear in the photos, especially away

continued on page 60

Griffin (standing) and Hudson in the studio. At right, their Lunar Utility Vehicle.

One's an artist,

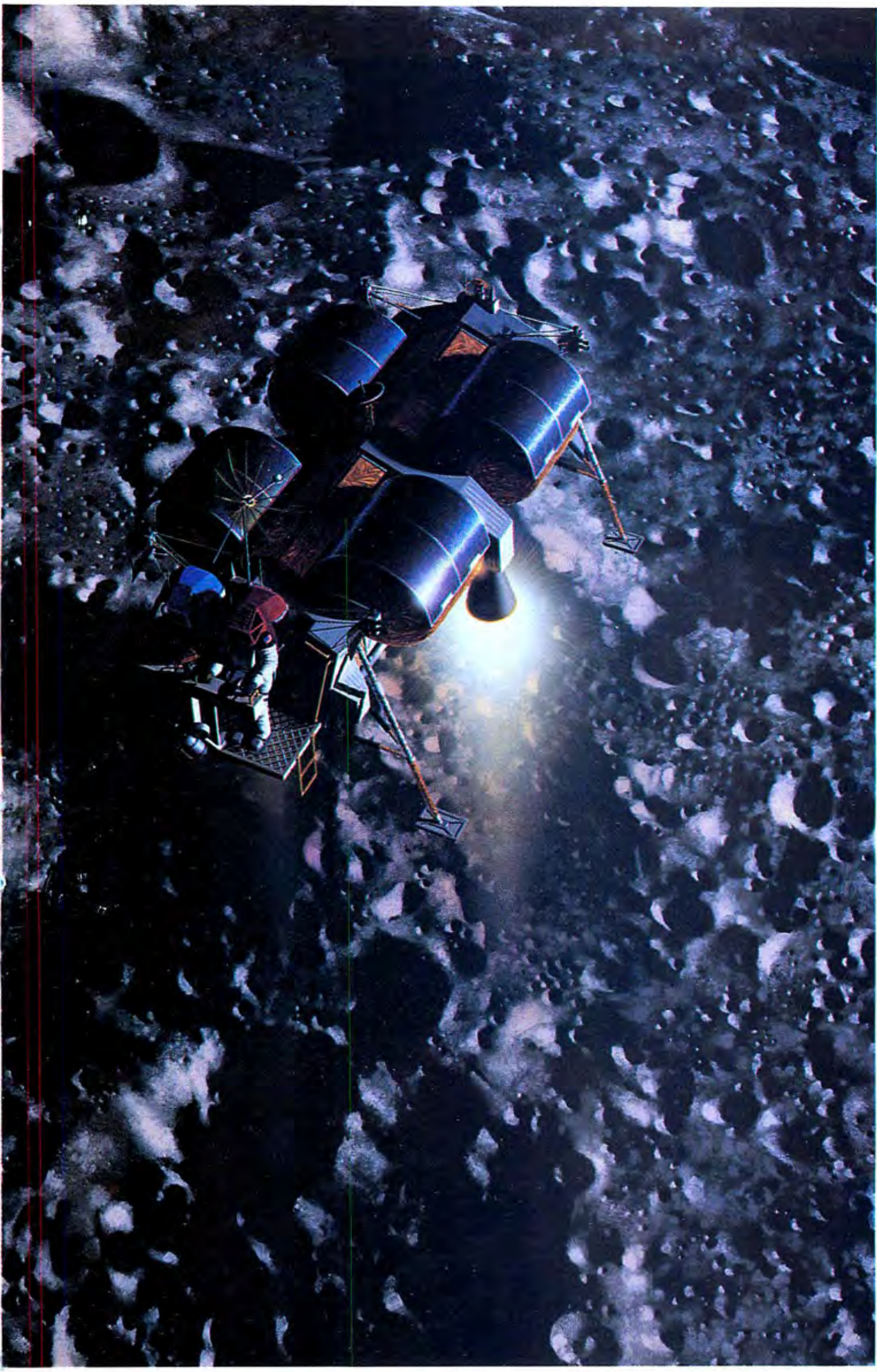
the other's an engineer.

Together they'll show you

pictures of the future.

BY JEROME RICHARD

The Drea


GRIFFIN/HUDSON

n Team

In the early days of the space shuttle, when NASA was first kicking around the idea of a "Space Flight Participant" program, the categories of people considered most likely to become the first private citizens to orbit the Earth included teachers, writers, TV reporters—and artists. If things had gotten that far, Paul Hudson would have been a leading candidate.

But even before the Challenger accident postponed the program indefinitely, Hudson says he wouldn't have gone. He would love to fly on the shuttle, but thinks the few onboard seats should be allotted to specialists with essential missions, not to spectators.

Anyway, he travels to space almost every day. He does it in his studio, where some of the hardware for future space missions begins in the imaginations of Hudson and his collaborator, aerospace engineer Brand Griffin.

Born in the frontier state of Alaska, the sandy-haired artist has been an enthusiast of space travel since the day he watched the Apollo astronauts take that first small step on the Moon in 1969. He was nine years old then, living in California.

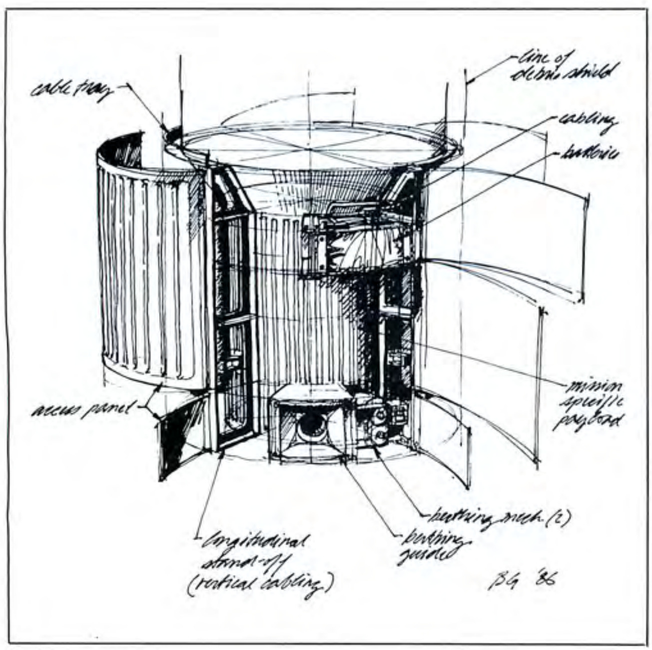
The wonder of that event still shines through the square, boyish good looks of the mature, professional artist Hudson is today. As a child he wanted to be an astronaut, and in high school he started out majoring in science and minoring in art. But as the space program seemed to slow down in the 1970s and the planets remained unexplored, he realized that he "could get to these worlds a lot faster by painting them." He switched his major and minor around, and after graduation enrolled at the Art Center College of Design in Los Angeles.

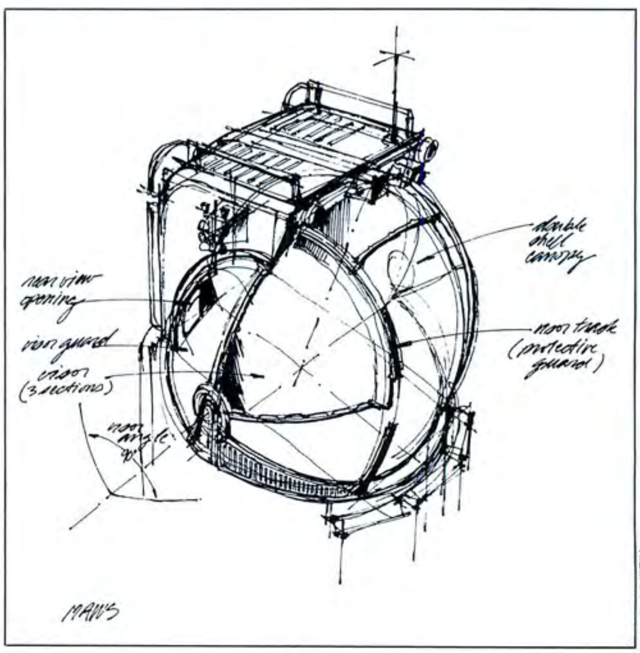
Hudson's first professional job was at Disney's Epcot Center in Florida, where he designed spacecraft and undersea colonies. After freelancing for a while, he answered Boeing's call to work as an artist depicting the space station designs of a young engineer named Brand Griffin.

Two years later, the entrepreneurial spirit seized Hudson again, and he returned to freelancing. His work has been commissioned by NASA, *National Geographic*, Time-Life, the President's National Commission on Space and several private corporations. Then last year, he and Griffin teamed up again for a series of paintings of space hardware published as a calendar. A new partnership, called "SpaceWorks," was born.

RAYMOND GENDREAU

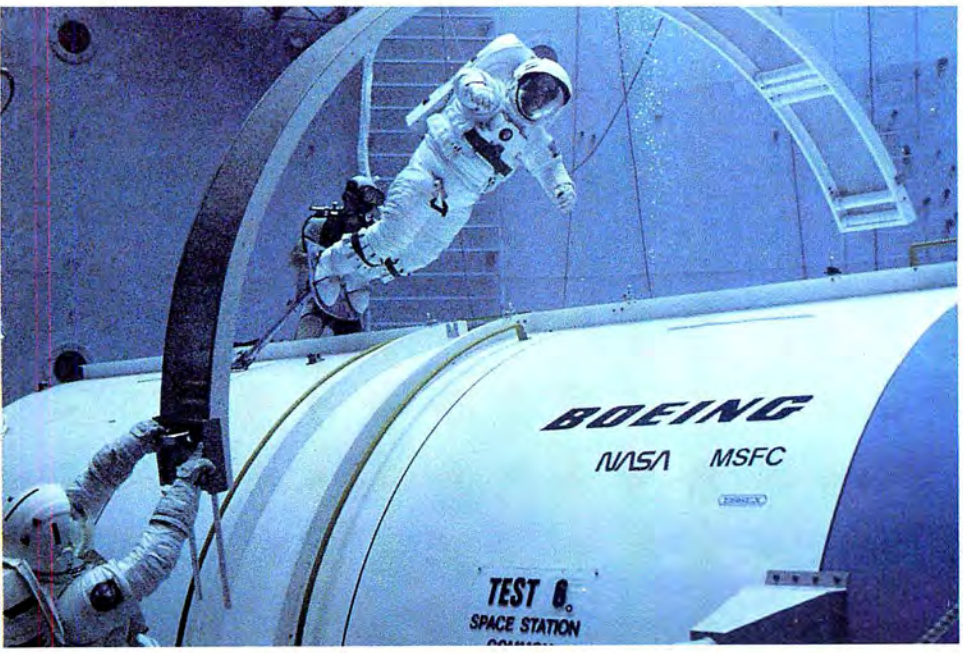
Hudson (above, at his drawing table) turns Griffin's sketches into finished paintings like this scene of a Manned Autonomous Work Station (MAWS) in the vicinity of a space station. Griffin's attention to detail—how a viewing visor opens, or where a spacecraft's cabling is stowed—comes from his own experience in designing and testing actual space hardware. Lower right: The engineer at work inside a weightlessness simulation tank.





BRAND GRIFFIN

GRIFFIN/HUDSON



BOEING AEROSPACE

At first glance, Hudson's pictures appear to be photographs. Then you remind yourself that we haven't yet put a camera on the surface of Neptune, and that it will be years before astronauts skip over the surface of Mars with portable jet packs strapped to their backs. The dramatic realism of Hudson's work is the result of the intensity of his imagination and a devotion to detail he shares with Griffin.

"I want to be on the Moon," Hudson says. "I want to be flying that craft. The only way for me to do that right now is to paint it as realistically as possible."

The paintings usually begin with Griffin's engineering sketches. In his job at Boeing, he directs the design of the habitation modules, or living quarters, for NASA's Space Station Freedom, scheduled for launch in the mid-1990s. Hudson describes his partner as a "driving force" and "a genius." The only problem is that Griffin works in Huntsville, Alabama, and Hudson about 40 miles from Seattle. Hudson says they keep Federal Express in business.

Griffin has architecture degrees from Washington State and Rice University, where his Master's thesis, not surprisingly, was on the design of a space station. He also has extensive knowledge of engineering and human physiology. Griffin manages to be pleasant and intense at the same time. He has won the Prix de Rome study fellowship, as well as three NASA faculty fellowships to work at the Spacecraft Design Division at the Johnson Space Center. A pilot and experienced scuba diver, he believes in personally testing what he designs. He has flown NASA's zero-g aircraft, and has spent many hours in space suits, in the simulated weightlessness of a "neutral buoyancy" tank.

It was Sputnik that first attracted Griffin, 42, to space. He read some science fiction when he was a kid, but, like Hudson, prefers nonfiction. "Nothing," he says, "is more unpredictable than fact."

After working all day designing the space station for Boeing, Griffin goes home and works on the even more advanced projects that Hudson will turn into models and paintings. When they actually get together, they talk about space travel with the knowledge of veterans and the enthusiasm of kids.

Unlike the space hardware dreamed

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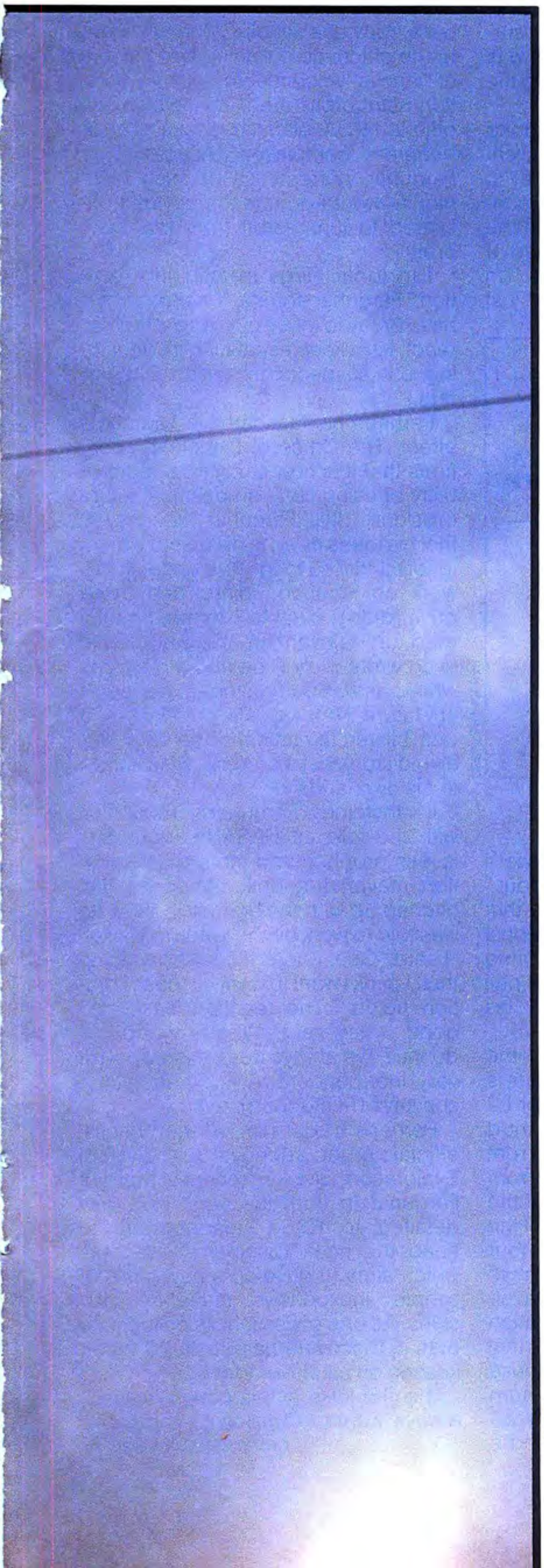
GOOD LIBRATIONS



TIM REDEL

Persistent. Stubborn. Prima donna. Robert Farquhar figures those are his good *qualities when it comes to championing the use of libration points.*

By Devera Pine

Robert Farquhar has had this thing about libration points for 30 years. To prove it, he pulls a dog-eared copy of his doctoral thesis out from under one of the neat piles that completely cover his double-width desk in the advanced mission planning section of NASA's Goddard Space Flight Center. Then he points out how few changes he's made—in bold red ink—since the document was written.

What has piqued Farquhar's interest for so long is

the practical application of libration points—mathematical and physical curiosities that exist in a two-body planetary system such as the Earth and the Moon. There are five of these locations, usually labeled L1 through L5, where gravitational pull and centrifugal force exactly balance. They're also called Lagrangian points after Joseph Lagrange, the French mathematician who first thought of them in 1772.

Farquhar thinks that NASA should be using libration points—combined with such orbital tricks as swinging spacecraft around the Moon or Earth to pick up speed—to save fuel and increase the size of interplanetary spacecraft. Because of the neat balance of forces at a libration point, a space station placed at the distance of the Moon's orbit, but exactly *opposite* the Moon, would be able to maintain that stable position using relatively little fuel. The cost in fuel of moving the station from one libration point to another also would be negligible.

So far, only one mission has ever made use of libration points—the ISEE-3, or International Sun-Earth Explorer project, launched in 1978. That craft, designed to study the solar wind, went into what's known as a "halo" orbit around one of the Sun-Earth libration points. (In a halo orbit the craft doesn't sit at the libration point, but circles slightly above and below the plane of the planets.)

Despite the success of the mission, however, Farquhar laments that the idea of libration point orbits still hasn't really caught on for human spaceflight applications. Perhaps it's partly because ISEE-3, instead of peacefully living out its days monitoring the solar wind, was transformed into the headline-making "International Cometary Explorer."

In a move that earned him nationwide newspaper coverage, a letter from President Reagan, and the admiration of schoolchildren (they wanted his autograph), Farquhar reprogrammed the craft to fly past comet Giacobini-Zinner in 1985. He accomplished this in part by swinging the craft around the Moon to gain speed—five times. The last of these passes was so low (75 miles above the lunar surface), that colleagues joked he was about to add "Farquhar's Furrow" to the Moon's cratered face.

Though ISEE-3 was never designed to observe comets, the mission went well; the craft was the first ever to fly to one of the icy dustballs. But the conquest of the comet overshadowed the earlier success of having placed a spacecraft in a libration point orbit. "I'm tired of [ISEE-3] being known for just the comet portion of the mission. That's the only thing anybody knows about," Farquhar says. In fact, he claims that when it comes to human missions, NASA headquarters is all but ignoring his work on the subject—and he'll pull every trick in the book to get his arguments heard.

According to Farquhar, one of the most economical ways to go to Mars is to set up a way station at the L1 or L2 point in the Sun-Earth system. You'd launch your Mars spaceship from either of these points—not from Earth—and you'd use swingbys of the Moon and Earth to give you much of the energy you'd need for the trip. Your Mars craft never comes down to Earth—a shuttle does that job, traveling from low Earth orbit to the libration point. One advantage of this plan is that NASA wouldn't have to choose between a Mars program and a return to the Moon. It's a relatively simple matter to transfer from an orbit around a Sun-Earth point to an orbit around an Earth-Moon point, says Farquhar, so you'd be able to do both trips with the same hardware.

Problem is, NASA's Office of Exploration, which is planning strategies for reaching Mars and the Moon, has shown little interest in libration points until very recently. From another one of the piles on his desk, Farquhar fishes out a copy of a stinging letter he wrote to the office, complaining that the use of "innovative concepts" such as libration point orbits aren't conspicuous in official NASA plans because of their "inherent complexity." According to Farquhar, correct use of such techniques would double the payload delivered to lunar orbit from low Earth orbit.

"I try to stir things up until I get a reaction," Farquhar admits. "I wonder what I have to say to those guys to get them to react. I just keep escalating it." (Including, one suspects, by talking to reporters.)

Perhaps his tactics have had some effect. The Office of Exploration confirms that it is now studying the possibility of using libration points in future missions. Still, Farquhar is annoyed that his ideas have, in his opinion, been ignored for too long: "I've done all this work on libration points, and these guys [didn't] even talk to me. So they wind up reinventing the wheel." He even wrote Sally Ride about his plans when she was putting together a report on future NASA goals in 1986—she didn't listen to him either, he says. "It's an old story that a prophet is not known in his own land."

If anything, Farquhar's reputation with the folks at NASA headquarters is less prophet, and more a combination maverick-nudnik. When he first hitched up with the agency in 1960, he was told to work on the Saturn 5 rocket. "I said, 'Gee, I don't think I'd like doing that. I think I want to work on these libration points.' The reaction wasn't too good—they said, 'Who is this prima donna?' I've always been this way—I'm very independent. Ask my secretary; she says I'm stubborn, too."

Perhaps to get him off their backs, officials at the agency's Solar System Exploration Division recently brought Farquhar in from the cold. He's now detailed to NASA headquarters to head the new "Discovery" program, which aims to develop a new class of simple, inexpensive planetary missions. As one of Farquhar's colleagues puts it, Discovery has declared "open season on all clever ideas."

If some folks in this country haven't always wanted to listen to Farquhar's

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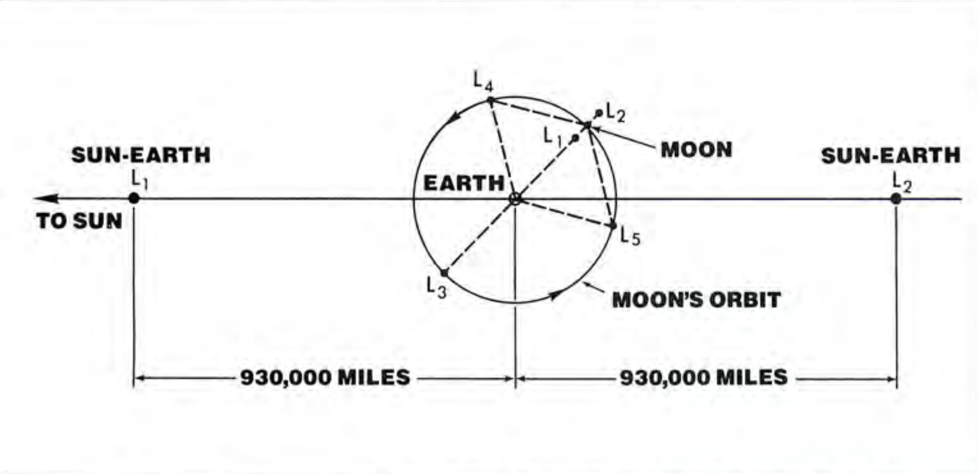

ROBERT FARQUHAR

A space station would stay "anchored" at any of the Earth-Moon or Earth-Sun libration points.

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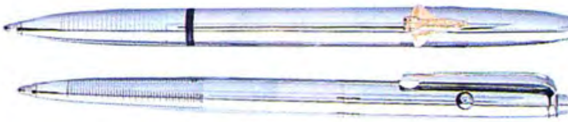

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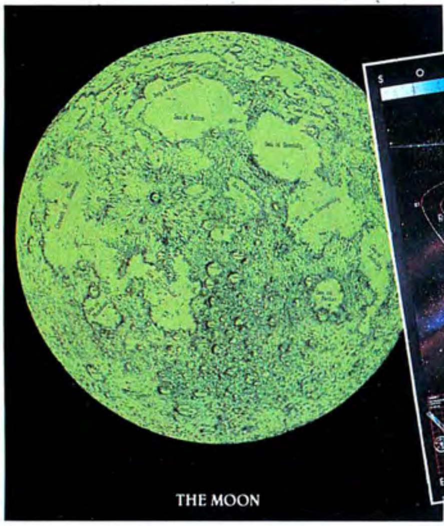

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REVIEWS

Journey Into Space
By Bruce Murray
W. W. Norton and Co.
381 pages. $19.95

By Robert M. Powers

Despite the publisher's blurbs, which call *Journey Into Space* "the first comprehensive history of America's space program," the book is mainly about exploring the planets with *unmanned* (or "unwomanned," as Sally Ride would have it) spacecraft—specifically, those designed by the Jet Propulsion Laboratory (JPL) when the author was a scientist and, later, the director there. Along the way, Murray attempts to give an insider's view of the decline and fall of the American space program.

It is a history of nearly mythological proportions. It begins long, long ago in a country far, far away, when there was a Knight named Kennedy in a whiter-than-white space suit. After Kennedy, there was a Fall into Darkness, in which the Evil Ones, who lived in wretched and benighted lands called Texas and Washington, used the powers of Inability, Incompetence, Budgetary Constraints and Great Blindness to make a monster of paper-clip teeth and xerox-copy tentacles, which they called The Shuttle, and which they sent out across the great nothingness to the Land of Pasadena, where the Sun still shone, to annoy and harass the righteous.

After Kennedy, says the author, no inspired presidential leadership materialized, and "mediocrity followed." He blames the space shuttle for nearly everything since the Great Flood. NASA, he says, "mortgaged America's future in space in a desperate bid to retain the shuttle as its means, and the ill-conceived space station as its end. In the process, NASA killed off the unmanned exploration of the Solar System."

He defines Apollo as "reality," the space shuttle as "fantasy," and declares that "Russia, not America, leads in the peaceful international exploration of space." He does not clearly define exactly *why* the space station was so "poorly conceived," nor does he do much more than rehash a great deal of what has come out about the shuttle since January 1986.

Journey Into Space is a NASA-bashing book, something nearly every publisher in the country commissioned almost before the parts of the destroyed Challenger had settled to the ocean floor. Predictably, such books are full of marvelous hindsight.

Murray, referring to the propulsion problems with the shuttle's Inertial Upper Stage (IUS): "At every curve along this trail toward calamity, a solution was obvious to us at JPL."

At the heart of Murray's angst is that many space science missions were delayed—and some cancelled—because NASA would only allow them to be flown on the shuttle, which suffered teething problems that are now well known and documented. In this *Murray* is correct: The decision by NASA to abandon expendable vehicles was a serious blow to unmanned space exploration, and is now recognized as a mistake.

As a respected scientist and a principal player in some of the most fantastic missions of exploration in this or any other century, Murray had an opportunity to tell the real story of the "Golden Age" of unmanned planetary exploration. Instead, the reader gets a healthy dose of what sounds a good deal like sniveling.

The book does contain some good insider stories: Murray relates the demise of JPL's solar sail mission concepts in a wry fashion and describes how the Voyager 2 spacecraft lost its hearing for a frantic interval when the project team simply forgot to send a critical command. He mentions the JPL staff's "10 pound per Mars mission" weight gain (the only canteen at the time was an ice-cream machine), and tells a good tale about naming the craters on Mercury.

But the fun soon ends in the dreary polemics: On page 168 we come upon Jimmy Carter calling JPL to extend his congratulations on the success of Pioneer and ask questions about the mission. Murray writes, "No President had better understood space technically..."

But on page 257, Carter is described as, "...the most scientifically illiterate President since Thomas Jefferson," because Carter had favored the Gamma Ray Observatory mission for funding over Murray and JPL's brainchild of a Halley's Comet flyby.

It is in his chapter about the proposed Halley flyby that Murray rages most furiously. In a book that devotes only 40-odd pages to the exploration of Mars by four Mariner probes, four Vikings and several ill-fated Soviet missions, Murray flogs on for 50 pages about the never-funded Halley mission that would have, in the author's words, "become a symbol for all America, signifying its return to leadership in space exploration."

The American public must be misinformed. They are under the delusion that those great pictures of Mercury, Mars, Jupiter, Saturn, Uranus and all those fabulous moons came from American spacecraft. Thanks mainly to this same Bruce Murray and JPL. And, having just watched live pictures from Neptune on the six o'clock news, we find that Galileo will be launched after all, as will the Space Telescope, and a Mars Observer.

It's true that they could have been launched a decade earlier. That is regrettable, and certainly frustrating. It is hardly a tragedy, and it falls very short of the epic proportions of Decline and Fall, despite all of Murray's well-meaning efforts to prove otherwise.

Near the end of the book, the author makes an impassioned plea for a manned mission to Mars, mainly repeating the currently fashionable view that we will do it with the Russians and the Europeans.

I hope so. But if we do, Murray will have to play Dr. Faust to the evil shuttle and the odious space station. You can't get to Mars just by rubbing two sticks together. □

The Drawing Board

continued from page 23

other international partners are involved, the rover and sample return may become separate but complementary missions.

Either way, mission designers face some tough problems: how to "teleoperate" vehicles on the Martian surface when there's a 20-minute delay in receiving signals; how to make a rover smart and rugged enough to wander the Martian landscape unsupervised; how to slow down a heavy spacecraft by "aerobraking" in the thin Martian atmosphere, then land it accurately on the surface.

The good news is that solving these problems will go a long way toward making it possible for humans to follow in the wheel-prints of the rovers, sometime in the next century.

Comets and Asteroids

If you judge by the sheer number of missions on the drawing board, asteroids and comets must be the most interesting objects in the Solar System. Beginning with **Galileo's** first-time-ever flyby of two main-belt asteroids—Gaspra and Ida—in 1991 and 1993 on its way to Jupiter, no fewer than five asteroids and four comets are awaiting robotic visitors in the next 15 years.

NASA now has a standing policy to fly past an asteroid for close-up study whenever a spacecraft crosses the main belt between Mars and Jupiter on its way to the outer Solar System. So, following the example of Galileo, the **Cassini** spacecraft is scheduled to investigate the 50-mile-wide carbonaceous asteroid Maja in March 1997, and one more asteroid encounter may be possible as the spacecraft heads toward its meeting with Saturn in 2002.

Closer to home, planners at NASA headquarters are thinking of cheap and easy ways to send a spacecraft to one or more of the so-called near-Earth asteroids. Although only a few dozen have been identified, statistical studies suggest that as many as 1,000 "Earth-crossers" may exist that are larger than half a mile in diameter. If so, they may provide a valuable supply of raw materials for future space industry, and therefore have more than just scientific interest.

Building on earlier studies of a **Near-Earth Asteroid Rendezvous,** the space agency's new "Discovery" program of small, quick planetary missions is considering these Earth-crossers as a prime target for a future mission, either an extended rendezvous, or—more likely, due to cost—a simple flyby or series of flybys. Like the moons of Mars, the near-Earth asteroids can be reached with relatively little expenditure of energy.

To rendezvous with several of these asteroids in one mission, however, would require more energy. Most designs for a multiple rendezvous mission call for some kind of ion drive, probably solar electric propulsion, a technology that has yet to be developed for planetary spacecraft.

For years, the Soviets have been discussing an asteroid mission called VESTA, named after one of the brightest and largest of the main-belt bodies. At one time the project was to have been a French/Soviet collaboration, until the French dropped out. The idea is still alive, however, according to Soviet academician Valery Barsukov, who outlined plans for the newly re-christened **VESTA/ASTER** mission at a recent international conference. Barsukov spoke of a spacecraft encountering five to six asteroids and one short-period comet over the course of its lifetime. Such a mission could be launched, he claimed, as early as 1997.

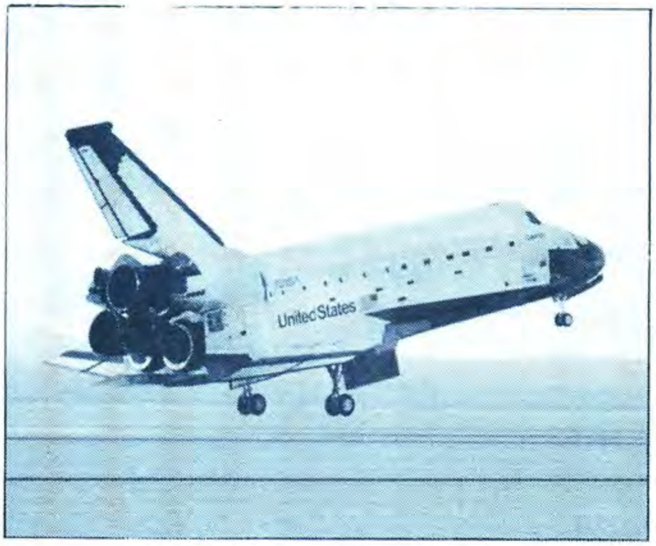
Other nations' near-term plans to study comets have more to do with resuscitation than with new launches. In 1986, a whole fleet of spacecraft from the Soviet Union, Japan and Europe converged on that most famous comet of them all, Halley. Now the European Space Agency (ESA) plans to see if its probe, called Giotto, is up for another assignment. On or about February 19, 1990, ESA will use NASA's Deep Space Network to try and reactivate the spacecraft and check the health of its scientific instruments. Although Giotto was battered by dust at Halley, most of its sensors are believed to be functional. If the camera is still working, then the **Giotto Extended Mission** is on.

Shortly after it left Halley, Giotto's orbit was adjusted to bring it back for a flyby of Earth in July 1990. If the extended mission is approved, controllers will fine-tune the trajectory before that flyby, in late March or early April, to send the probe toward a July 1992 meeting with a comet called Grigg-Skjellerup. Japan's more limited entry in the Halley armada, called Suisei, may also be re-targeted, for a 1998 encounter with the comet Giacobini-Zinner.

The most ambitious of the near-term plans for cometary exploration, by far, is NASA's **Comet Rendezvous Asteroid Flyby (CRAF),** scheduled for launch in 1995. Along with the Cassini Saturn mission, CRAF received "new start" money from Congress for 1990. Both missions will use the new Mariner Mark 2 spacecraft for outer Solar Sys-

MISSION FILE

STS-28



LAUNCH:
8:37 A.M. EDT, August 8, 1989, Pad 39B, Kennedy Space Center, Florida

LANDING:
6:37 A.M. PDT, August 13, 1989, Edwards Air Force Base, California

ORBITER:
Columbia

ALTITUDE:
184-195 nautical miles

CREW:
Brewster H. Shaw, Jr., Commander
Richard N. Richards, Pilot
David C. Leestma, James C. Adamson, Mark N. Brown, Mission Specialists

PRIMARY PAYLOAD:
Classified. Believed to be large photo-reconnaissance satellite

OTHER PAYLOADS:
Classified. Possibly related to Strategic Defense Initiative (SDI)

Shuttle mission 28 was little noted, and probably will not be long remembered, which is unfortunate. From the tidbits of information that leaked out, Columbia's five-day classified flight apparently was one of the most interesting military shuttle missions conducted to date.

After a brief delay caused by haze and ground fog, Columbia executed a flawless liftoff and thundered up into the bright Florida sky. The moment of ignition is a thrill for any "rookie" astronaut, but co-pilot Dick Richards got more than he bargained for: His seat jerked backward about an inch as Columbia lunged away from the pad.

Seconds later, the shuttle stack performed a stately pirouette and thundered off toward the northeast, confirming pre-launch speculation that the mission's orbital track was designed to overfly much of the Soviet Union. Watchers at the Cape clearly saw the shuttle's solid boosters separate two minutes after liftoff, and the fuzzy glow of the orbiter's three main engines remained visible in long-range tracking cameras almost to the point of engine cutoff.

A certain amount of silliness about "security" attends these shuttle missions for the Department of Defense, and STS-28 was no exception. NASA officially blacks out communications between the astronauts and Mission Control during ascent—yet they were clearly audible to reporters eavesdropping with common UHF radios. The media representatives even included Soviet journalist Nugzar Ruhadze, covering the launch as part of an exchange program with Atlanta television station WXIA.

There also was the usual guessing game about Columbia's secret cargo. Analysts agreed that the crew would launch a spy satellite, probably a spacecraft able to transmit high-resolution images of Soviet military targets to the ground. A minority opinion favored another radar-imaging "Lacrosse" satellite, similar to one deployed by Atlantis' STS-27 crew last December.

Whatever Columbia was hauling in its payload bay, some aspects of STS-28 left even veteran shuttle-watchers scratching their heads. Even on classified flights, the crew normally releases their primary payload during the shuttle's first few orbits to ensure mission success if a problem forces a premature return to Earth. But as Columbia went round and round, only two small objects were spotted flying in formation with the orbiter. Ground observers were unable to track anything the size of a large, maneuverable reconnaissance satellite. ("Maybe they launched a B-2 [Stealth bomber]," one wag suggested.) By mid-August, the U.S. Space Command still had catalogued only the two payloads initially reported.

Surprisingly, it was Air Force Secretary Donald Rice who broke the official silence on Columbia's mission. "The United States now has a satellite in orbit as the result of a very successful launch," Rice boldly announced as the astronauts wrapped up their third day in space. "We were extraordinarily pleased, as were our colleagues in NASA, that everything went so well."

There was another sign that perhaps even the Pentagon was becoming bored with playing spy vs. spy. The Air Force nonchalantly revealed Columbia's orbital parameters...while NASA, as is its custom during military flights, insisted that the information was still secret.

The astronauts devoted at least one day of their flight to a thorough checkout of Columbia's refurbished systems, which suffered a couple of minor glitches dur-

Shaw, Adamson, Leestma, Brown and Richards (l. to r.) emerge after their secret flight.

ing the mission. One of the orbiter's maneuvering thrusters failed and had to be disabled shortly after Columbia reached orbit. And early in the mission, it was rumored that a fire had broken out in the crew compartment. NASA later explained that the teleprinter in the spaceplane's middeck area had experienced an electrical short that caused a small spark and a puff of smoke. Neither set off Columbia's sensitive smoke alarms.

Near the end of their fifth day in orbit, the crew buttoned up Columbia and began their fiery reentry through the atmosphere. Swooping in from the north, Brewster Shaw and Dick Richards brought the spaceliner in for a dusty but perfect touchdown on Edwards' lakebed runway. "A super team—and a great machine," boasted capsule communicator Frank Culbertson in Mission Control. "Welcome home, Columbia!"

There were no cheering throngs to greet the astronauts, however. In the interests of "national security," the public had been banned from Edwards. Only reporters were allowed to witness the landing—and even they had to scramble for a view when a power failure knocked out television monitors in the media trailer.

Columbia came through Mission 28 with only a few dings on its thermal tiles, which should aid a quick "turnaround" for the veteran shuttle orbiter. The spaceliner has a critical appointment on its next flight, scheduled for December 18: retrieval of the Long Duration Exposure Facility (LDEF) before atmospheric drag causes the schoolbus-sized satellite to fall from orbit.

SPACE SHUTTLE MISSIONS FOR THE DEPARTMENT OF DEFENSE

MISSION	DATES	ORBITER	PROBABLE PAYLOAD
STS-4	6/27 - 7/4/82	Columbia	Infrared telescopes (Not a dedicated DoD flight)
STS-51C	1/24 - 1/27/85	Discovery	Signals intelligence electronic eavesdropping satellite
STS-51J	10/3 - 10/7/85	Atlantis	Two Defense Department communications satellites
STS-27	12/2 - 12/6/88	Atlantis	Lacrosse radar reconnaissance satellite
STS-28	8/8 - 8/13/89	Columbia	Photo-reconnaissance satellite
STS-33	11/19/89*	Discovery	Signals intelligence satellite
STS-36	2/1/90*	Atlantis	Unknown
STS-38	7/9/90*	Discovery	Unknown
STS-44	3/4/91*	Discovery	Unknown
STS-48	8/22/91*	Atlantis	Starlab (DoD Spacelab mission)
STS-76	12/16/93*	Discovery	Unknown

***PLANNED LAUNCH DATE AT PRESS TIME**

tem missions, with a combined cost of $1.6 billion.

Now that Giotto and the other Halley spacecraft have done their quick fly-bys, it's time to rendezvous with a comet, stay with it through thick and thin and watch its transformation from a passive Sun-circling iceball to an active, dust-spewing wonder.

That's exactly what CRAF will do. It will photograph and analyze its traveling companion, a comet called Kopff, capture and analyze samples of gas and the dust that will be spewing out at the rate of some 600 pounds per second, and even send a metal-tipped "penetrator" to pierce the comet's icy heart.

CRAF also will inspect and map the entire comet from up close, during both its quiet and active phases, under different lighting conditions and with a whole battery of spectrometers and cameras.

The spacecraft is planned for launch in August 1995. Over the course of its eight-year lifetime, it will fly past and photograph a 50-mile-wide, main-belt asteroid called 449 Hamburga (named in 1899 for the city of Hamburg), then fly on to match orbits with Kopff in August 2000, where it will remain for at least two and a half years.

The penetrator is perhaps the most interesting part of the mission. On July 20, 2001, the 32nd anniversary of the Apollo 11 landing, CRAF's golf tee-shaped penetrator will make one small step for cometary science as it separates from the main spacecraft to fly the two and a half mile distance to the comet's icy nucleus. Its speed will be some 130 feet per second. The impact will be hard—up to 350 g's. As the giant golf tee penetrates to a depth of three feet, accelerometers will measure the impact to determine the strength of the nucleus (engineers are preparing for anything up to the hardness of solid ice).

Once in place—and for approximately the next week—the penetrator will determine the composition of the nucleus and take temperature readings with instruments ranging from a gamma ray spectrometer to a gas analyzer, then will relay data back to the main CRAF spacecraft.

CRAF's intimate dance with a comet will be state-of-the-art science, but it won't be the ultimate. Eventually, researchers want to have a piece of comet for themselves. Japanese scientists have been discussing the possibility of a **Coma Sample Return** spacecraft that would trap samples of dust in a special gel as it flew through the dusty coma of a comet. Then there is **Rosetta** , a European nucleus sam-

ple return mission planned for early in the next century.

If Rosetta is approved as a new ESA mission in 1992, a Mariner Mark 2-derived carrier spacecraft (the main U.S. contribution to the project) could be launched as early as January 2001. The "reference mission" now under study would have the spacecraft meet up with the comet Churiumov-Gerasimenko in 2005. After several weeks of photographing and studying its quarry at close range, a penetrator with a radio navigation beacon would be shot into the comet near the desired landing site.

The European-built landing vehicle would then follow. After anchoring itself to the nucleus, the lander's robotic arm would use a core drill to collect up to ten pounds of material and place it in a cryogenically cooled sample container, which would lift off from the lander platform to rejoin the main spacecraft in orbit near the comet. A three-year cruise would bring the sealed container and its precious cargo back to Earth, where it would re-enter the atmosphere and parachute down to the surface to be recovered by eager cometary scientists in November 2008.

Why all the interest in these tiny chunks of rock and ice? Scientists generally believe that comets and asteroids are small pieces of the Solar System's past. While the surfaces of the planets and large moons have been constantly reworked by bombardment, erosion and volcanic activity, these smaller bodies may have remained relatively unchanged since they formed billions of years ago.

If comets and asteroids do offer a "Rosetta Stone" for understanding the origins of our own Solar System and perhaps others, then it would be of interest both to astronomers and to exo-biologists who try to reconstruct how life could have developed from bits of carbon, hydrogen and other elements floating among the stars.

With a fleet of comet missions on the drawing board, maybe we'll soon find out.

JUPITER

The long-delayed **Galileo** mission finally gets underway this year, and so begins the second generation of outer Solar System exploration (see page 28). What the Pioneers and Voyagers passed by in a hurry, Galileo will inspect up close over the course of a leisurely, two-year tour.

After Galileo, there are no firm plans for Jupiter missions, but there are always ideas. A panel of the National Research Council suggested several options in its 1988 report, *Space Science in the Twenty-First Century.* Galileo's tour through the equatorial regions of the Jupiter system could be followed by a magnetospheric polar orbiter, then by a deep atmospheric probe that would explore regions inaccessible to Galileo.

Eventually, we would also want to turn our attention to the Jovian moons, beginning with an Io lander to explore that volcanic moon's violent relationship with its parent planet. After that, could a lander to crack Europa's icy shell be far behind?

SATURN

What Galileo does for Jupiter, the **Cassini** project will do for Saturn. With start-up funding recently approved by Congress, the U.S./European mission (named after the discoverer of several Saturnian satellites) is now on track for a launch in April 1996.

Following flybys of Earth and an asteroid on the way outward, Cassini will fly through the tail of Jupiter's magnetic field on its way to a rendezvous with Saturn in October 2002.

There it will stay for four years, circling the ringed planet, exploring its icy moons and ring system with a full suite of spectrometers, cameras, and fields and particles sensors, and paying particular attention to the cloud-covered moon Titan, which it will study at close range with imaging radar on each orbit. After some 35 to 40 Titan flybys, more than 70 percent of the moon's surface should be mapped.

Then, an even closer look. Five months after arriving at Saturn, in March 2003, the European Space Agency's Huygens probe (named after Titan's discoverer) will be released from the main orbiter to descend by parachute for three hours through the moon's thick atmosphere. Mission designers expect that the probe will survive its impact on the surface to keep transmitting data, although this is not guaranteed. (Project scientists have been using the Very Large Array of radio telescopes in New Mexico to try and discover whether Titan's surface is solid or liquid, to give them some idea whether Huygens will land with a thump or a splash.)

Whatever is on the surface will appear in panoramic photographs taken by the probe as it descends through the atmosphere, sniffing the gases, looking for lightning and conducting other experiments. None of this will be a snap—among other technical problems, Huygens' engineers have to figure out how to deploy a parachute at Mach 1.5, or one and a half times the speed of sound. If they suc-

ceed, though, those three hours at Titan will be the highlight of what may be the decade's most exciting planetary voyage.

After Cassini ends its main mission in September 2006, future expeditions to Saturn will likely go deeper into the atmosphere or explore the planet's polar regions. A Titan lander (or floater) is inevitable, and a ring rendezvous mission to study Saturn's dizzying bands of icy moonlets has also been proposed for the 21st century.

Uranus and Neptune

It may seem premature to talk about going back to Uranus and Neptune, considering that Voyager 2 just left there. And it is. Eventually, we'll want to send the same kinds of long-lived orbiters now on the drawing board for Jupiter and Saturn. But given the long travel times to the outer Solar System, and the full plate of already approved planetary missions, it's unlikely that Uranus and Neptune orbiters will fly until well into the next century. And that means we'll probably wait until nuclear electric propulsion comes along.

"Ion drive" engines could revolutionize the exploration of the outer Solar System by cutting travel times down to a few years, and making certain missions—for example, a Miranda lander—possible.

In this way, human and robotic exploration will be linked. The same ion drive engines developed to send cargo ships to Mars for human expeditions could also be used by planetary robots that would open up new worlds to explore.

Pluto

Finally, there's Pluto. Despite the fervent hopes of a small "Pluto Underground," (*Final Frontier*, October 1989), a mission to the last planetary holdout is not high on NASA's list. The reason, of course, is that it takes too long to get there— longer than most scientists, or congressional appropriations committees, would care to wait.

Still, if the costs can be kept down, NASA is interested in a Pluto flyby as one option for its new "Discovery" series of cut-rate planetary missions. A small spacecraft could be piggybacked onto an asteroid mission, or onto the Solar Probe proposed for the next century, or onto any flyby that takes advantage of a gravity assist from giant Jupiter.

However it gets there, by the time a Pluto mission arrives at its destination, we may have identified nearby stars with planets of their own, if they exist.

So don't worry. There will always be someplace new to explore.

Galileo

continued from page 31

for nearly two years will keep astrophysicists busy well into the next century ("like having a black hole in your backyard as a play toy," project scientist Torrance Johnson once remarked). We may find out if the processes at work in Jupiter's magnetosphere are similar to what is occurring in faraway objects such as quasars and pulsars. Closer to home, long-term study of the donut-shaped ring of ions circling the planet along its magnetic equator could further our understanding of Earth's own magnetosphere.

The Galileo mission also is expected to add immensely to our understanding of Jupiter's beautiful, yet mysterious, weather systems. The Voyagers observed the swirling cloud masses for only a few weeks and raised as many questions as they answered. Despite numerous detailed images of the hurricane-like Great Red Spot, for example, we don't really understand where it came from, why it continues to exist, or what its true structure is.

No one claims that Galileo will solve all of Jupiter's puzzles. But the opportunity to examine the planet's turbulent belts, zones and spots and the way they interact over a period of months will give Jupiter weather-watchers the same advantage enjoyed by their Earth-based colleagues. And it's just possible that Jovian meteorological studies might yield some insights into some of Earth's strange and often unpredictable climatological phenomena.

By the time Galileo finally achieves Jupiter orbit, many of its designers will be dead, or entering their eighties. As Galileo traces out its Jovian mandala, it will be steered, interrogated and pampered by people who are younger than the mission itself. And almost certainly, the mission will pose a whole new set of questions to be addressed by some future generation of robotic explorers....

Jupiter yet again fills the sky ahead of me, its stormy cloud tops resembling marbled paper—or swirls of colorful oil floating on water, stirred by the titanic finger of God Himself. The mission for which I was built is complete, but I will continue circling, my orbit intricately interlaced with those of the Jovian moons.

Perhaps, some day, they will come to take me home.

Ron Miller is an illustrator specializing in astronomical subjects, and is co-author of The Grand Tour, Out of the Cradle *and* Cycles of Fire.

Voyager

continued from page 27

keep on coming, climbing sharply as we near the ring plane. Later we will learn that Voyager is experiencing 300 impacts per second; when played on audio tape, it sounds like a heavy rain on a tin roof. Just before a planned break in transmissions, we see the dust begin to tail off. Thankfully, nothing larger than a micron—the size of a particle of smoke—strikes the spacecraft.

At JPL, scientists toast the news of the successful ring-plane crossing with champagne, while Voyager slips behind Neptune. Just before flying into the planet's shadow, the spacecraft trains its sensors on the gaseous horizon. As the Sun sets, Voyager measures its dimming light, recording clues to the structure of Neptune's upper atmosphere.

Some 49 minutes later, Voyager emerges from Neptune's shadow, heading for Triton, the last and—project scientists are hoping—one of the most dramatic "stops" on the entire 12-year itinerary. Triton is an oddball moon, circling Neptune backwards, on a path that is highly inclined with respect to Neptune's equator. Seasons on Triton vary in a strange, erratic cycle that repeats every 600 years. Today, the satellite's southern hemisphere, well into spring, basks in the dim light of the Sun. Its northern hemisphere, meanwhile, is in the midst of an unspeakably cold, continuous night that will last for decades.

Voyager's early images of Triton have shown that it is somewhat smaller than scientists expected, about 1,700 miles across. It is a peculiar looking place, rendered in pale hues of pink and blue, a color combination unknown anywhere else in the Solar System.

4:05 a.m.

Geologist Larry Soderblom is discussing one of the early Triton images. Even from these far-off views, the moon shows signs of having undergone great changes. Its surface is very bright—whiter than new snow—and, apparently, free of large craters. It must be covered with fresh ice, and that suggests some kind of volcanic activity has reworked its surface.

In this frigid realm where moons are composed mostly of ice, Soderblom says, scientists speak of "cryo-volcanism" and of "lavas" composed not of molten rock but of water. It's too early for Soderblom to do more than speculate; these early images show only enough detail to be tantalizing. Now, in the small hours, we wait for the closeups.

The highest-resolution images of Triton will take great engineering prowess. Sunlight at Neptune is a thousand times weaker than at Earth, requiring Voyager's cameras to make unusually long exposures. But because the spacecraft is travelling so fast, it will have to track Triton like a photographer taking pictures from a streaking automobile. Otherwise, the images would be hopelessly blurred. If it works, the high-resolution views of Triton should show features as small as a city block. Whatever they show, those pictures will be a miracle.

6:40 a.m.

The first closeups of Triton appear on the screen, and they are almost beyond comprehension, unlike anything else in the Solar System. The bright ground of the south polar region fills the frame, mottled with wisps and splotches of bright and dark, a maze of detail. Another image is even stranger: The darker equatorial region is revealed as a network of cracks, dimples and ridges reminiscent of a ripe melon. Indeed, the scientists will nickname this "cantaloupe terrain."

On a different part of the surface, great cracks transect the textured ground, branching from one another like strange icy superhighways. Still another region is marked by vast, smooth expanses, as if an ocean has frozen in place. Only rarely do we notice amid the strangeness the comfortingly familiar sight of a crater.

And yet there is something uncannily familiar about the pictures. They evoke a jumble of mental images of other worlds— the smooth white face of Jupiter's moon Europa, Uranus' Ariel, even the wind-streaked deserts of Mars. We can't resist indulging in a bit of instant science, offering our own analyses. At JPL, in the Voyager project's inner sanctum, so are the scientists. Project Scientist Ed Stone will later tell the press, "We were all standing around with our mouths hanging open, just like you."

7:20 a.m.

A beautiful summer morning has bloomed beyond our windows. Sunlight warms the slate roof of the church across the way, under the rich greens of maple leaves. Opposite, on the monitor, is the ghostly limb of an ice world at the edge of the Solar System, like some deep-sea creature caught in the glare of a strobe light. Suddenly the great interplanetary gulf seems very real, and Voyager seems like a trespasser in the twilight.

For sheer intellectual adventure, nothing quite compares to that first

moment of discovery. But over the next few days a more detailed portrait of Triton will emerge. The moon is cloaked by an exceedingly thin atmosphere (surface pressure: ten millionths of that on Earth) composed mostly of nitrogen with a hint of methane, which extends nearly 800 miles above the frozen surface. Triton's surface temperature is a mind-numbing 400 degrees F below zero, making it the coldest known place in the Solar System.

The moon's frozen-water surface is probably covered by a layer of nitrogen and methane frost in constant motion. Over the course of each 165-year season the frost evaporates in the areas exposed to the weak rays of the Sun, then migrates to the moon's dark, frigid regions, where it condenses again as frost until the sunlight returns.

The Voyager scientists offer evidence of a remarkable life history. Triton's frozen-water crust has apparently been melted and re-frozen several times. But what made Triton so warm? Perhaps the moon's strange orbit is a clue: It may have begun as an interplanetary wanderer that strayed close enough to Neptune to be captured by the giant planet's gravity. The process could have been so stressful as to melt Triton's icy interior, resulting in outpourings of water onto the surface. Today, we see the frozen snapshot of that era, which may have ended some two billion years ago.

In Voyager's photos, Triton's south polar frost cap is criss-crossed with streaks of darker material. They bear a striking resemblance to streaks on Mars that are attributed to deposits of windblown dust. But Triton's winds are far too weak to move dust around—unless the dust were already airborne. Soderblom makes a surprising, it's-crazy-but-it-might-just-work suggestion: The streaks emanate from small, still active volcanoes. As little as 60 feet below the surface, depending on how much heat is in Triton's interior, conditions might be right for nitrogen to exist as liquid. Soderblom is betting that it's there. If the liquid were to migrate upward along cracks, so his theory goes, it would turn to gas in a geyser-like explosion that would send a plume of nitrogen frost and bits of the icy, dusty crust flying perhaps 20 miles into the air. On the way down the frost and dust would be carried downwind, as much as 50 miles from the point of eruption, and would be laid down as a long, streak-like deposit.

It's an elegant theory, and Soderblom gets at least tentative agreement from other members of the science team. The scientists' job of interpreting these strange photos—and all the other Neptune data that will keep coming in until the encounter ends in early October—is only now beginning.

Having presented us with such exotic notions as nitrogen ice volcanoes, Voyager gives us something far simpler and just as memorable as it leaves: a postcard from the edge of the Solar System, showing Neptune's slender crescent with Triton's smaller crescent just beyond. The crescent is a familiar image from the Voyager encounters; it means goodbye.

It's hard to think of that August night, and of other similar nights in the past 12 years, and not feel sadness. Voyager has given us great gifts—it has made distant worlds known. They are now ours in a way they never were before. It will probably take the rest of a lifetime to fully appreciate that gift, and by then Voyager's real journey will have barely started. Look into a dark, starry sky some night and try to fathom *that* trip. ☐

Andrew Chaikin wrote about the Apollo missions in the July/August issue. His book about the men who went to the Moon and their experiences is forthcoming from Viking Press.

The Dream Team

continued from page 37

up by science fiction writers, whose conceptions have to work only in terms of their stories, the Griffin-Hudson inventions are designed to function in the real environment of space.

Griffin takes a systems approach. He has to know how everything will work, where the astronauts will sit, and in what positions. When he designs a space suit he knows that in zero-gravity, bodily fluids are not distributed the same way they are on Earth. Radiation hazards must also be considered, and astronauts who spend time on the Moon or Mars may have to wear shielded underwear to protect their reproductive systems (adding a new urgency to the command, "Get the lead out!").

When one of Griffin's designs arrives, Hudson sets to work translating it into a realistic painting. The first step is a proportional drawing to get all the dimensions and measurements exactly right. Then he creates a pen and ink composition, setting the design in its intended environment. The next step is to build a scale model called a "proof of concept," to see if the design works in three dimensions and to study the way light strikes it. A photograph reduces the model back to two dimensions. Finally, Hudson starts on the finished picture, applying acrylics, marking pens, Crayolas, "whatever works" to gessoed gator board. To depict the surface of the Moon, the artist finds Earth rocks of similar shape and substance, paints them to resemble Moon rocks, then studies the way light falls on them. The models—clay astronauts and styrene space ships— remain in Hudson's studio when the work is complete, but NASA has shown some interest in using them for educational purposes, he says.

The Griffin-Hudson inventions are designed to function in the real environment of space.

▼ ▼ ▼

The next, more ambitious step for Griffin and Hudson will be to construct full-scale mock-ups, including a working man-machine loop, of some of their creations. One design is a Lunar Utility Vehicle, or LUV, capable of vertical take-offs and landings so it can traverse the rugged lunar terrain. Another is the Advanced Lunar Suit, which will have vital information stored on voice-activated microchips in the suit itself, so that when an astronaut talks to himself, he'll get answers.

The Manned Autonomous Work Station, or MAWS, is an updated version of Wernher von Braun's "Space Bottle" concept—a small, autonomous module with robotic arms that can be maneuvered around a larger space station. Air pressure inside the MAWS would equal the pressure in the station, so the astronaut can work in shirt sleeve comfort, free to use his hands for everything from manipulating the controls to scratching an itch. At present, an astronaut leaving the shuttle must work in a clumsy space suit, spend time adjusting to the change in pressure, and don a Manned Maneuvering Unit to have the same mobility.

Five years before President Bush's Moon-Mars initiative announced last summer, Griffin had begun designing a permanent camp to house astronauts when they get there. The first astronaut to set foot on Mars will receive all the acclaim, but if Griffin and Hudson don't

get there first in their imaginations, the trip will probably be impossible.

There is a precedent for the Griffin-Hudson collaboration, which the painter describes as a partnership between a left-brained and a right-brained person. Back in the 1950s, scientist Wernher von Braun and artist Chesley Bonestell also worked together, and it's interesting to compare the streamlined craft they designed to the gawky-looking machines we are actually sending into space.

Bonestell is one of Hudson's heroes. Another is John Wayne, whose poster graces the artist's studio as a symbol of the pioneering spirit that will take us into space.

Hudson has much of that spirit himself. With his family, he is building his own house, studio and stables in the foothills of the Cascades. Next year, Hudson, his wife and his father-in-law will ride horseback from Mexico to Alaska, a journey he says has never been done before. The trip will be sponsored by *National Geographic*.

"It's all one big adventure," the 29-year-old artist says, with a gesture that indicates the horseback trip, space and life itself. His children, a boy nine and a girl seven, won't go along on this trip. But Hudson sees plenty of adventure ahead for them: "They're the people who are going to colonize the Moon."

Space exploration is not just an adventure to Hudson, it's a mission, one he believes is an American duty.

"America," he insists, "has a responsibility to carry people to the stars." He describes the vision quest of the American Indian, young men going out into the wilderness in search of a glimpse of their destiny.

"Space exploration is America's vision quest," he says. If young people could get high on space travel, he believes it might give their lives more meaning. That's another reason his pictures are so realistic. He wants space travel to come alive for those kids.

"From earliest times," Hudson says, "the Moon gave us something to look up at. It was the impetus to go higher."

An artist painting realistic pictures of what does not yet exist. John Wayne sharing a studio with an astronaut. Suddenly, the seeming incongruities of his career merge into one vision. If somewhere in the western United States next year, you see a man on horseback looking up at the Moon, say hello to Paul Hudson. □

Jerome Richard is a freelance writer in Seattle. His last article for Final Frontier *was on space tourism.*

Good Librations
continued from page 40

ideas, a lot of other people have. At the moment, one of his pet projects is working with the Japanese to set up a comet sample-return mission with the awkward acronym "SOCCER" (Sample of Comet Coma Earth Return). His plans for the mission call for a simple spacecraft equipped with even simpler scientific equipment—panels that would unfold to collect particles as the craft flies by the comet.

To keep the spacecraft's weight (and launch costs) down, Farquhar wants to send it out to its targeted comet via a swingby of the Moon, which provides a gravity boost. In fact, the entire mission is designed with cost control in mind. "This is the El Cheapo way to do it," he says.

Farquhar managed to get NASA interested in the project, in his own way: "Don't give away my trade secrets, but I kind of tell [the Japanese], 'Hey, NASA is really interested in doing this.' And then I go back to NASA and say the Japanese are interested."

In Farquhar's scenario, NASA would provide the collection panels and, possibly, a camera system. The agency also would track SOCCER with its Deep Space Network antennas and pick up the craft with the shuttle and an Orbital Maneuvering Vehicle. Here's where Farquhar's creativity comes in handy again; to save on the weight of a heat shield, SOCCER won't be designed to re-enter the Earth's atmosphere. Instead, the craft will "aerobrake"— that is, go through the Earth's atmosphere a little at a time to cut down on its speed. It will take about 100 passes to get the craft low enough so that the OMV can pick it up. If the maneuver isn't done correctly, the craft would simply burn up.

The Soviets are interested in Farquhar's ideas, too: In 1995 they plan to launch a craft called IKI-2. Since the mission is part of an international program to study the Sun and the Earth which also involves the United States, Farquhar has seen preliminary plans: IKI-2 will be placed in a small halo orbit. But, says Farquhar, the way the Soviets plan to go about it will use up a lot of fuel.

"We know that the way to get there is to use a lunar swingby on the way out—then you can cut [fuel use] down to zero," he says. "So I talked to their guy at our last meeting. I'm just telling them about Newton's laws; it's no big secret."

Another problem with the Soviet plans has to do with their calculations for a double lunar flyby. Farquhar digs out an illustration of their plans and

laughs. "They were close, but it's wrong," he says. "It won't work, because it goes under the surface" — which is Farquhar's offhanded way of saying the spacecraft actually will *hit* the Moon, according to his calculations. As a result of these observations, he was asked to visit Russia last April (the invitation referred to him as a "dynamic scientist").

"Farquhar's first criterion is 'what's in it for me'," he jokes. With the Japanese SOCCER mission, that meant he got to go to Japan for four months as a visiting professor at the Institute of Space and Astronautical Science. (He now happily gives away business cards from that trip—one side is in English, the other in Japanese.) With IKI-2, it meant a trip to Russia: "The Russians invited me over there, they treated me nice, I got a trip to the Soviet Union." And, he adds, "I got to learn a lot about *their* plans."

Farquhar still has a few tricks up his sleeve. For instance, he could send ISEE-3, which is making a long journey back from comet Giacobini-Zinner, back to its original halo orbit to study the solar wind. "All these scientists were griping that we took it. We didn't take it, we just borrowed it." (ISEE-3 will return to Earth's neighborhood in 2014.)

Or, he could press the European Space Agency to let Goddard take over the Giotto probe that flew by comet Halley in 1986: "If they find out in 1990 that the camera [on the craft] isn't working, ESA has no plans to use it [again]. But the space physics instruments are working; NASA could use it for that. Why don't they just let us have it then? It could be retargeted to go to another comet."

And, of course, Farquhar is available to help calculate lunar swingbys and halo orbits for anyone who asks—provided Goddard Space Flight Center gets the credit. "They get JPL [the Jet Propulsion Laboratory] or Lewis Research Center or one of those guys to call me up, and they want to come down here and get all our program software. I tell them how to do a lot of this stuff, and there's not even a single reference to Goddard.

"There's a lot of competition between the [NASA] centers," Farquhar continues, quarrelsome as ever. "I'm willing to help people out, but they have to be honest about it." □

Devera Pine is a Long Island-based freelancer who writes often on health and technology.

Hubble

continued from page 33

from the highly-trafficked ecliptic plane where the planets orbit the Sun—ground-based telescopes could be immediately trained on them to try to confirm their existence.

Apart from exploring our own planetary neighborhood, another prime concern is the possible existence of other solar systems. Some of the first "guaranteed time" observations will search for evidence—direct or indirect—of these extrasolar planets. Even though Hubble's mirror is on the cutting and polishing edge of technology, it may be unable to resolve actual images of a small, dark planet orbiting a bright, distant star. But there are other ways to identify planetary "companions." One is to check for minute wobbles, visual and spectrographic, in the motions of stars that may indicate gravitational tugs by large planets. Another is to search for circumstellar material around young, newly formed "T-Tauri" stars—matter that may eventually develop into a planetary system.

Using a far-seeing instrument like the space telescope to observe nearby objects will not be without its logistical problems. Unlike stars and galaxies, which for practical purposes remain fixed against the stellar background, planets, satellites and other "moving target objects" are more difficult to chase with an orbiting telescope.

"You have to program the telescope to follow the motions of these closer targets," explains Weaver, and the closer an object is to Earth, the faster it will move across the field of view.

After the first year of operation, when Hubble's idiosyncrasies will have been worked out, scientists at the Space Telescope Science Institute plan to set aside blocks of telescope time for planetary observations. Collectively called the Planetary Campaign, these chunks of viewing time will give the astronomical community a chance to conduct planetary "missions" without ever leaving home, and to build on the knowledge gained by such planetary spacecraft as Viking and Voyager.

"Unlike deep space objects," says Brown, "we understand a great deal about the planets of the Solar System. Being at this level of [astronomical] maturity means that the kinds of investigations we are now doing are no longer for pure discovery, although there will be discoveries. Now we are asking deep analytical questions based on what we know." □

Patricia Barnes-Svarney is a freelance writer in Endwell, New York.

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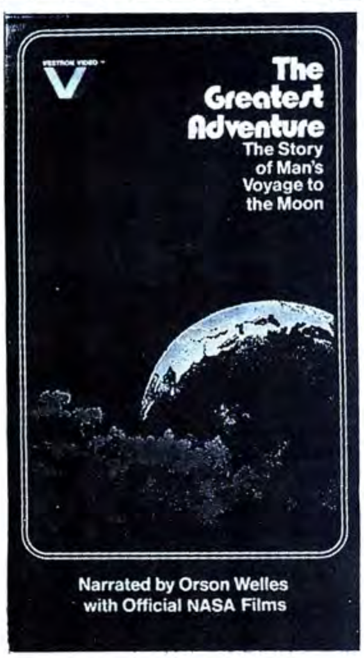

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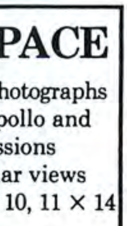

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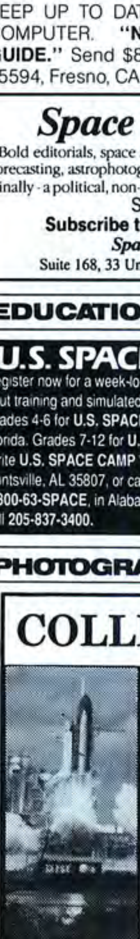

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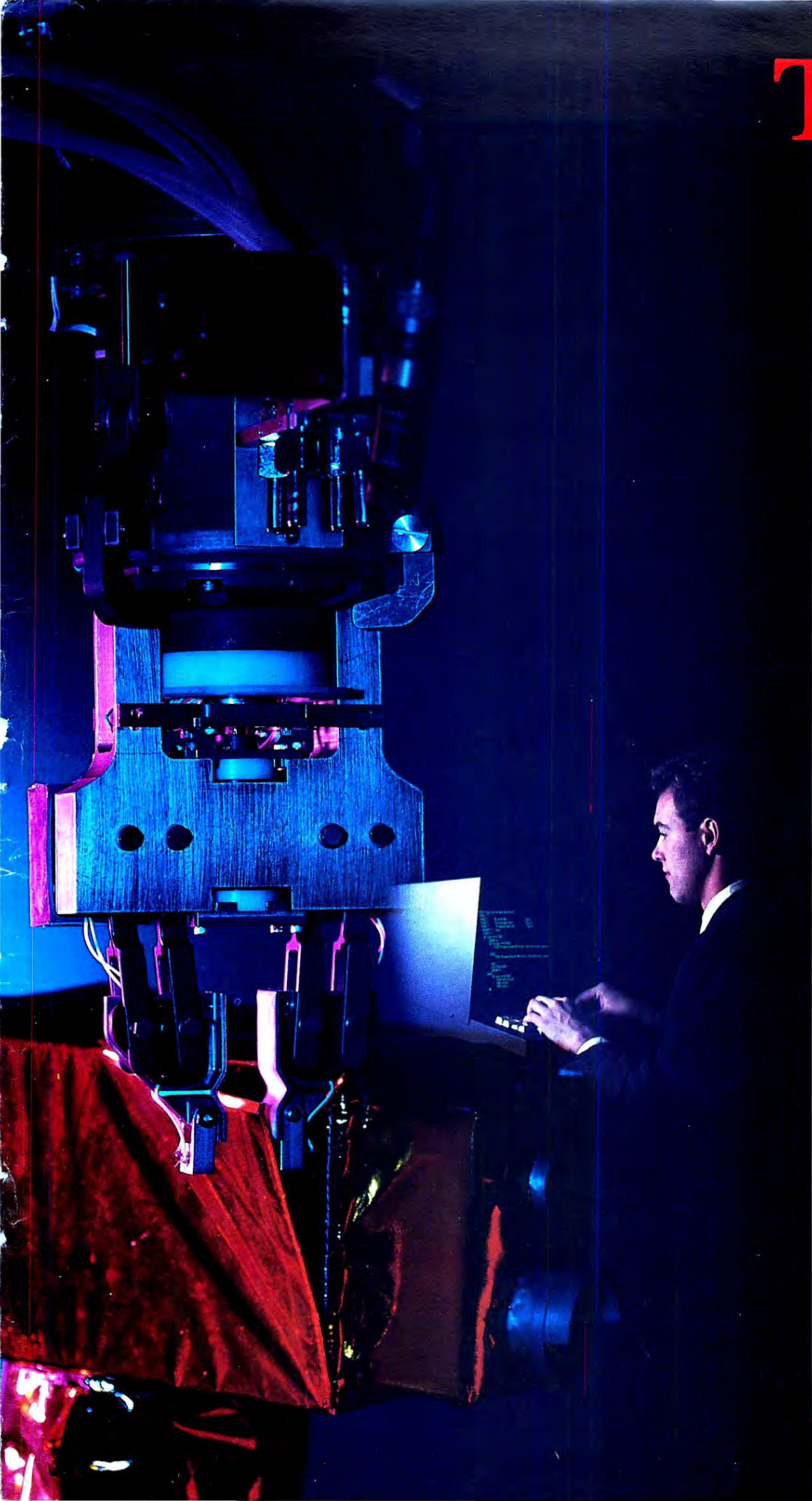
on the far horizon
will find his right road.

Dag Hammarskjold, 1964

Dave Scott looks out from the open hatch of the Apollo 9 command module, March 1969.



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